AEDC-TSR-78-V24

AUGUST 1978

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HEAT-TRANSFER, SURFACE-PRESSURE, AND BOUNDARY-LAYER SURVEYS ON CONIC AND BICONIC BODIES WITH BOUNDARY-LAYER TRIPS AT MACH NUMBER 6 - PHASE I

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Period Covered: January 23, 30, and 31, 1978

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Worldway Postal Center
Los Angeles, California 90009

ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: AEDC-TSR-78-V24
2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): Heat-Transfer, Surface-Pressure, and Boundary-Layer Surveys on Conic and Biconic Bodies with Boundary-Layer Trips at Mach Number 6 - Phase I
5. TYPE OF REPORT & PERIOD COVERED: Final Report January 23, 30-31, 1978
6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): Frederick K. Hube, ARO, Inc., a Sverdrup Corporation Company
8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Arnold Engineering Development Center, Air Force Systems Command, Arnold Air Force Station, TN 37389
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: Program Element 63311F, Control No. 627A-00-8
11. CONTROLLING OFFICE NAME AND ADDRESS: SAMSO/RSSE, P. O. Box 92960, Worldway Postal Center, Los Angeles, CA 90009
12. REPORT DATE: July 1978
13. NUMBER OF PAGES: 70
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)
15. SECURITY CLASS. (of this report): UNCLASSIFIED
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE: N/A
16. DISTRIBUTION STATEMENT (of this Report): Approved for public release; distribution unlimited.
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)
18. SUPPLEMENTARY NOTES: Available in DDC.
19. KEY WORDS (Continue on reverse side if necessary and identify by block number): boundary-layers, hypersonic flow, trips, conic bodies, biconic bodies, transition, heat transfer, pressure distribution
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Heat-transfer data were obtained on a 7-deg cone and a 14/7-deg biconic model to determine the minimum size distributed roughness required to bring boundary-layer transition near the model nose. Surface pressure and boundary-layer surveys were also obtained on a few configurations in an attempt to identify the difference in the characteristics of naturally turbulent boundary layers and those tripped with distributed roughness. Data were obtained at a nominal Mach number of 6 at Reynolds numbers ranging from 1 x 10^6 to 4.7 x 10^6 per foot. Most of the data were obtained at zero angle of attack although some data were

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obtained at angle of attack for a few selected bluntness/trip combinations.

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NOMENCLATURE

H (TO)	Heat transfer coefficient based on To, BTU/ft^2-sec-°R
M_∞	Freestream Mach number
P_o	Tunnel stilling chamber pressure, psia
P_∞	Freestream static pressure, psia
q_∞	Freestream dynamic pressure, psia
Re_∞, Re_∞/ft	Freestream Reynolds number, ft^{-1}
T_o	Tunnel stilling chamber temperature, °R
V_∞	Freestream velocity, ft/sec
X, XSURF	Model surface length, in.
α	Model angle of attack, deg
ϕ	Model roll angel, deg
ρ_∞	Freestream density, slugs/ft^3
Θ	Body surface angle
ω	Circumferential location of pressure orifice and heat gages (positive clockwise looking upstream), deg

1.0 INTRODUCTION

The work reported herein was sponsored by the Space and Missile Systems Organization (SAMSO), Air Force Systems Command (AFSC) and the Research Division of the Directorate of Test Engineering (DOTR), of the Arnold Engineering Development Center (AEDC), AFSC under Program Element 63311F AF control number 627A-00-8. The work was performed by ARO, Inc., AEDC Division, (A Sverdrup Corporation Company), contract operator of AEDC, Arnold Air Force Station, Tennessee. Project monitors were Capt. R. J. Chambers and Mr. E. R. Thompson for SAMSO and AEDC, respectively. ARO project monitor and principal investigator was Dr. M. O. Varner. Inquiries to obtain copies of the test data should be directed to either of the following: SAMSO/RSSE, P. O. Box 92960, Worldway Postal Center, Los Angeles, CA 90009, Attn: Capt. R. J. Chambers; AEDC/DOTR, Arnold AFS, TN 37389, Attn: E. R. Thompson. A copy of the final data is on file in microfilm at AEDC.

Tests were conducted in the 50-in. Diam Hypersonic Wind Tunnel (B) of the von Karman Gas Dynamics Facility (VKF) on January 23, 30, and 31, 1978, under ARO Project No. V41B-W6. The objective of the test was to determine the smallest boundary-layer trip which was effective without producing flow-field disturbances. This test phase was planned as a preliminary investigation for a more detailed study of boundary-layer trip influences.

Heat-transfer measurements were obtained to identify transition locations. Flow-field data were obtained with pitot probes and both shielded and unshielded total temperature probes. Model surface pressure and temperature distribution were also obtained. A new on-board probe system was also used during this test phase.

All data were obtained at a nominal Mach number of 6 at free-stream Reynolds numbers ranging from 1.0×10^6 to 4.7×10^6 per ft. Most of the data were obtained at angles of attack up to 14 degs. Configurations tested included a 7-deg cone and a 14/7 deg (i.e., a 14 deg fore cone section with a 7 deg aft cone frustum) biconic. Spherically blunted nose tips were tested with nose radii ranging from 0.050 in. to 0.500 in. Tests were also performed with the 7-deg sharp nose tip cone configuration.

2.0 APPARATUS

2.1 TEST FACILITY

Tunnel B is a closed circuit hypersonic wind tunnel with a 50-in.-diam test section. Two axixsymmetric controured nozzles are available to provide Mach numbers of 6 and 8 and the tunnel may be operated continuously over a range of pressure levels from 20 to 300 psia at $M_\infty = 6$, and 50 to 900 psia at $M_\infty = 8$. Stagnation temperatures sufficient to avoid air liquefaction in the test section (up to 1350°R) are obtained through the use of a natural gas-fired combustion heater. The entire tunnel (throat, nozzle, test section, and diffuser) is cooled by integral,

external water jackets. The tunnel is equipped with a model injection system, which allows removal of the model from the test section while the tunnel remains in operation. The general arrangement of Tunnel B is illustrated in Fig. 1.

2.2 TEST ARTICLE

Two model configurations were tested in this phase: (1) a 7-deg half angle cone with a virtual length of 40 in. and (2) a biconic model with a 14-deg half-angle forebody and a 7-deg afterbody (total virtual length of 29.849) as shown in Fig. 2. Nose radii of 0.050, 0.100, and 0.500 in. were tested on the conical model in addition to a baseline sharp nose configuration. The biconic model was tested with nose radii of 0.050 and 0.500 in. Model components were fabricated from Type 304 stainless steel.

The models were instrumented with pressure orifices and Gardon-type heat-flux gages. Table 1 (Appendix 2) lists the instrumentation locations and shows that the top centerline was the main ray of pressure instrumentation and the bottom centerline was the ray instrumented with Gardon gages. At three stations, pressure orifices were also installed at 90-deg intervals around the model.

Boundary-layer trips consisted of distributed roughness formed by Carborundum® grit, machined helical grooves or roughness generated by blasting the surface with grit. The geometry and location of the trips are shown in Fig. 3.

2.3 TEST INSTRUMENTATION

2.3.1 Test Conditions

Tunnel B stilling chamber pressure is measured with a 200- or 1000-psid transducer referenced to a near vacuum. Based on periodic comparisons with secondary standards, the accuracy (a bandwidth which includes 95-percent of residuals, i.e. 2σ deviation) of the transducers is estimated to be within ±0.25 percent of reading or ±0.30 psi, whichever is greater for the 200-psid range and ±0.25 percent of reading or ±0.8 psi, whichever is greater for the 1000-psid range. Stilling chamber temperature measurements are made with Chromel®-Alumel® thermocouples which have an accuracy of ±(1.5°F + 0.375 percent of reading) based on repeat calibrations (2σ deviation).

2.3.2 Test Data

The Tunnel B pressure system is equipped with 1- and 15-psid transducers which are referenced to a near vacuum. The system automatically selects the transducers and calibrated ranges for best precision for each pressure measurement. Based on periodic comparisons with secondary standards, the accuracy of these transducers (bands that include 95 percent of residuals i.e., 2σ deviation) is estimated to be ±0.2 percent of reading or ±0.01 psi, whichever is greater, for the 15-psid transducers and ±0.2 percent of reading or ±0.0015 psi, whichever is greater, for the 1-psid transducers.

2.3.3 Heat-Transfer Measurements

Heat-transfer data were obtained with 0.125-in. diam Gardon-type heat-flux gages with Iron-Constantan case thermocouples used to evaluate an effective wall temperature for determining heat-transfer coefficient and for monitoring the model structural temperature level and distribution. The estimated uncertainty in the gage calibration factor is ±5 percent. Details of this type of gage are available in Ref. 1.

2.3.4 Flow-Field Measurements

Two separate probing systems were used to perform the boundary layer and flow-field surveys. One system was attached to the model sting and was equipped with a pitot tube, an unshielded thermocouple probe, and a shielded thermocouple probe. An overhead probe system was mounted on the wind tunnel and was instrumented with a pitot tube and an unshielded thermocouple probe.

Both the shielded and unshielded thermocouple probes were made with Chromel-Alumel thermocouples which had an estimated uncertainty of ± (1.5°F + 0.375 percent of reading).

The sting-mounted pitot probe pressure was measured with the standard Tunnel B pressure system. Overhead system pitot pressure was measured with a 15-psid Druck® transducer which has an estimated uncertainty of ±0.009 psia. A near-vacuum reference pressure was used with the Druck transducer.

Near-vacuum reference pressures for the transducers used in this test were measured with a Hastings absolute pressure transducer.

2.4 SURVEY PROBES

2.4.1 Geometry Details

Both the overhead and sting-mounted pitot probes were fabricated by flattening a 0.024 in. O.D. (0.020 I.D.) tube as shown in Fig. 4. This procedure produced a probe tip thickness of 0.010 in. with an open slit of 0.005 in. height. The actual measured dimensions of the two pitot tubes used in this test are presented on Fig. 4.

Figure 5 illustrates the geometry of the unshielded (Fig. 5a) and shielded (Fig. 5b) thermocouple probes. The unshielded total temperature probe was fabricated by the VKF from a length of sheathed thermocouple wire (0.010-in. O.D.) with two 0.0015-in. diameter wires. The wires were bared for a length of about 0.015 in. and the thermocouple junction formed. The probe was used in this form without a shield. Figure 5b shows that a manufacturer-prepared thermocouple junction was installed through a insulating sleeve to form the shielded thermocouple probe. Four 0.0074-in. diam vent holes were drilled in the shield tube.

2.4.2 Calibration

The recovery temperature characteristics of each total temperature probe were calibrated in the inviscid portion of the model flow field and in the tunnel free-stream flow. Calibration data for the unshielded probes were expressed in the form of recovery factor as a function of Reynolds number. Shielded probe recovery was obtained as a function of both Reynolds number and Mach number.

2.5 SURVEY MECHANISMS

The overhead probe drive system illustrated in Fig. 6 was designed and fabricated by the VKF. The positioning mechanism is housed above a port in the top of the Tunnel B test section. Access to the test section is through a 40-in.-long by 4-in. wide floor opening which can be sealed by a pneumatically-operated door. Separate drive motors are provided to (1) insert the mechanism into the test section or retract it into the housing, (2) position the mechanism at any desired axial station over a range of 35 in. with a precision of ±0.01 in., and (3) probe a flow field of approximately 10-in. depth with a precision of ±0.001 in. The drive axis inclination of the probe support can be adjusted, but all surveys obtained during this test phase were taken with the probe travel normal to the model axis (i.e. no drive axis inclination). An offset strut was used in this test to permit surveys to be made near the model base. The strut is equipped with a pneumatically-operated shield to protect the probes during injection and retraction throught the tunnel boundary layer and during tunnel condition changes.

The sting-mounted probe package shown in Fig. 7 was designed and fabricated by the VKF. A drive motor and position potentiometer were enclosed in an "L"-shaped sheet metal housing which had water tubes for cooling. The system has a vertical drive with a position resolution of ±0.001 in. Total vertical travel of the system is approximately 4 inches.

Calibration of the probe drive was checked optically with an optical micrometer. Relative position and lateral spacing of the probes was also confirmed with an optical micrometer.

3.0 TEST DESCRIPTION

3.1 TEST CONDITIONS AND PROCEDURES

3.1.1 General

A summary of the nominal test conditions at each Mach number is given below:

M_∞	p_o, psia	T_o, °R	ρ_∞, Slugs/ft^3	V_∞, ft/sec	P_∞, psia	$Re_\infty/ft \times 10^{-6}$
5.91	55	845	2.98×10^{-5}	2981	0.037	1.0
5.94	131	|	7.06×10^{-5}	2982	0.088	2.5
5.95	250	↓	13.37×10^{-5}	2983	0.167	4.7

Table 2 contains a summary of all configurations and test variables.

The objective of this test phase was to determine the smallest boundary-layer trip that would bring transition near the trip without introducing disturbances in the flow field. A boundary-layer trip that brought the end of transition in the vicinity of the first heat gage (see Table 1 for gage locations) was considered effective and suitable to be studied in more detail. This initial approach was taken since the ultimate goal is to fix the end of transition on the forebody of the biconic configurations to be studied in detail in later test phases.

3.1.2 Data Acquisition

Transition location at zero angle of attack was determined from heat-transfer distributions obtained with the Gardon heat-flux gages. Prior to each run, the model was cooled by flowing air over the model to obtain a uniform wall temperature near room temperature (i.e. approximately 520°R). The model was injected into the tunnel flow for about five seconds while a continuous record of gage output was recorded.

Two additional types of heat-transfer data were obtained to provide information about the circumferential transition distribution at angle of attack. One data mode was performed by rolling the model at a fixed angle of attack while continuously recording the gage output. These data provided a circumferential map of transition location. The second dynamic data mode involved obtaining a continuous record of gage output with the model moving in the pitch plane at approximately 1 deg/sec. These data are useful in defining the movement of transition along the windward and leeward model rays with angle of attack.

Surface-pressure data were obtained on primary configurations such as the sharp cone baseline body and configurations with selected bluntness/trip combinations.

Flow-field surveys consisted of approximately 50 data points obtained at different heights above the model surface at a station 0.5 in. (surface distance) forward of the model base (see Fig. 8). The probe direction of travel was normal to the model centerline. Both total temperature and pitot pressure measurements were made simultaneously along with model wall pressure and temperature data at the probe station. Data were recorded after the pitot pressure had stabilized. The total survey distance probed was approximately 4 inches. Procedures used for both the on-board and overhead probes were identical.

Initial probe positioning on the model wall was monitored optically with a high resolution (525 lines/frame) closed-circuit television (CCTV) system. The camera was fitted with a telescopic lens system which gave a total magnification factor of 38 (from tunnel centerline to monitor picture). The television image was used to verify contact

between the pitot tube and the model wall before obtaining the first data point in a survey. Television monitoring also made it possible to evaluate the deflection of unshielded thermocouple probes caused by the aerodynamic loading. This deflection was estimated to be nominally 0.010 in.

3.2 DATA REDUCTION

Although some portions of the data reduction used in this study were fairly standard, the flow field probe data included an evaluation of several boundary layer parameters including the definition of the boundary layer thickness, displacement thickness, momentum thickness, kinetic energy thickness, and total enthalpy thickness. Also, special data reduction procedures were needed to correct the shielded and unshielded total temperature probe measurements. A complete summary of the data reduction procedures used in this study are included in Appendix III.

3.3 UNCERTAINTY OF MEASUREMENTS

3.3.1 General

The accuracy of the basic measurements (p_o and T_o) was discussed in Section 2.3. Based on repeat calibrations, these errors were found to be

$$\frac{\Delta p_o}{p_o} = 0.0025 = 0.25\%, \quad \frac{\Delta T_o}{T_o} = 0.005 = 0.5\%$$

Uncertainties in the tunnel free-stream parameters and the model aerodynamic coefficients were estimated using the Taylor series method of error propagation, Eq. (1),

$$(\Delta F)^2 = \left(\frac{\partial F}{\partial X_1}\Delta X_1\right)^2 + \left(\frac{\partial F}{\partial X_2}\Delta X_2\right)^2 + \left(\frac{\partial F}{\partial X_3}\Delta X_3\right)^2 \dots + \left(\frac{\partial F}{\partial X_n}\Delta X_n\right)^2 \qquad (1)$$

where ΔF is the absolute uncertainty in the dependent parameter $F = f(X_1, X_2, X_3 \dots X_n)$ and X_n is the independent parameter (or basic measurement). ΔX_n is the uncertainty (error) in the independent measurement (or variable).

3.3.2 Test Conditions

The accuracy (based on 2σ deviation) of the basic tunnel parameters, p_o and T_o, (see Section 2.3) and the 2σ deviation in Mach number determined from test section flow calibrations were used to estimate uncertainties in the other free-stream properties using Eq. (1). The computed uncertainties in the tunnel free-stream conditions are summarized in the following table.

		Uncertainty, (±) percent of actual value					
M_∞	$Re_\infty/ft \times 10^{-6}$	M_∞	p_∞	q_∞	Re_∞/ft	$\rho_\infty V_\infty$	ρ_∞
5.91	1.0	0.3	2.1	1.4	1.0	1.3	1.4
5.94	2.5	0.2	1.0	0.7	0.7	0.9	0.7
5.95	4.7	0.2	1.0	0.7	0.7	0.9	0.7

3.3.3

Model surface pressure and on-board pitot probe data uncertainties are discussed in Section 2.3.2. Summarizing, measurements at pressure levels at 1 psia or less have an estimated uncertainty of ±0.2 percent of reading or ±0.0015 psi, whichever is greater. Measurements above 1 psia have an estimated uncertainty of ±0.2 percent of reading or ±0.01 psi, whichever is greater. Overhead probe instrumentation is discussed in detail in Section 2.3.4 in which an estimated pitot pressure uncertainty is ±0.009 psia.

Total temperature measurements from both the shielded and the unshielded thermocouple probes is estimated to be ±(1.5°F + 0.375 percent of the reading). Consequently, because data were obtained under hot wall conditions (approximately adiabatic), the estimated uncertainty in the probe measurements throughout the flow field surveys is ±0.5 percent of reading.

The estimated uncertainty in Gardon gage calibration factors is ±5 percent. Overall uncertainty in the heat-transfer coefficient, H(TO), is estimated to be ±6 percent. After the uncertainty in free-stream values of density and velocity is considered, the overall uncertainty in Stanton number is estimated to be ±6.1 percent.

Based on optical observations and mechanical resolution the estimated uncertainty in probe position is ±0.002 in. As noted earlier in Section 3.2.2, deflection of the unshielded thermocouple probe was optically evaluated to be 0.010 in. This deflection was accounted for in the data reduction. This uncertainty in the axial position of the probe was ±0.050 in.

The uncertainties of all primary measurements such as pressure, temperature, heat flux rate, model attitude and free stream Mach number nonuniformity have been identified. The uncertainty in some of the free stream parameters have been identified, but the uncertainty in many of the other parameters (for example, boundary layer parameters) listed in the tabulated and plotted results of the final data fall outside the scope of this report.

3.4 DATA CORRECTIONS

The longitudinal heat-transfer distribution on the 7-deg cone showed more irregularity than expected based on the estimated uncertainty in the gage data. Consequently, a procedure was established to smooth the data by obtaining correction factors for the indicated heating level. The data distribution was compared with calculated turbulent and laminar heating data. Based on these comparisons, smooth fairings through the data were

obtained. A separate set of correction factors were obtained for the laminar and turbulent cases since these were the extremes in heating levels encountered. These two sets of correction factors were averaged and applied to the data. Correction factors were applied only to the 7-deg cone and the 7-deg conical afterbody. Data tabulations show both corrected and uncorrected data.

A correction for unshielded probe position was made to account for probe downward deflection resulting from aerodynamic loading. The deflection magnitude was determined from the television monitor screen and estimated to be 0.010 in.

4.0 DATA PACKAGE PRESENTATION

A complete set of test results in tabulated and graphical form has been transmitted to SAMSO (test sponsor) as a Final Data Package. The data computational procedures were checked by performing manual calculation verification of the computer calculations. Sample tabulated data and nomenclatures appear in Appendix IV.

5.0 REFERENCES

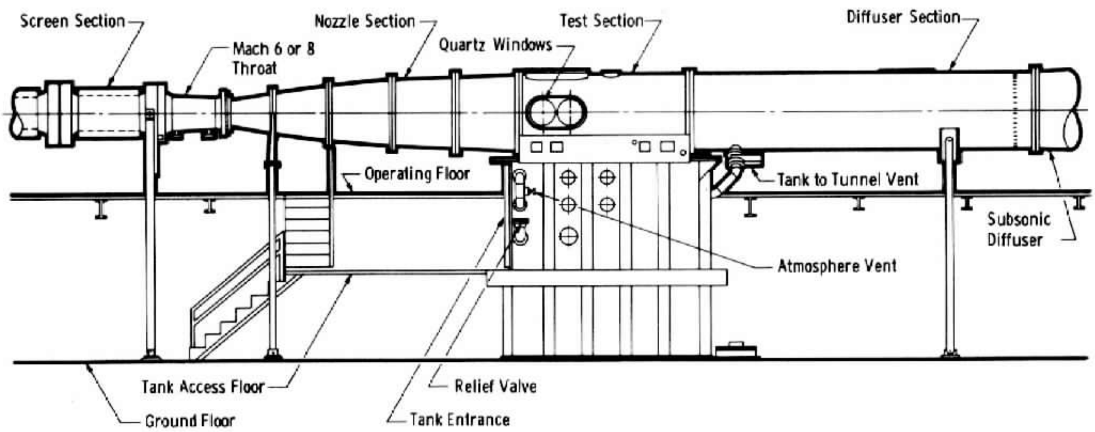
1. Trimmer, L. L., Matthews, R. K., and Buchanan, T. D. "Measurement of Aerodynamic Heat Rates at the AEDC von Karman Facility." International Congress on Instrumentation in Aerospace Simulation Facilities IEEE Publication CHO 784-9 AES, September 1973.

2. Robertson, S. James "On the Use of the Gardon Gage for the Measurement of Convective Heat Flux," Heat Technology Lab Memo 9, Huntsville, Alabama, June 1962.

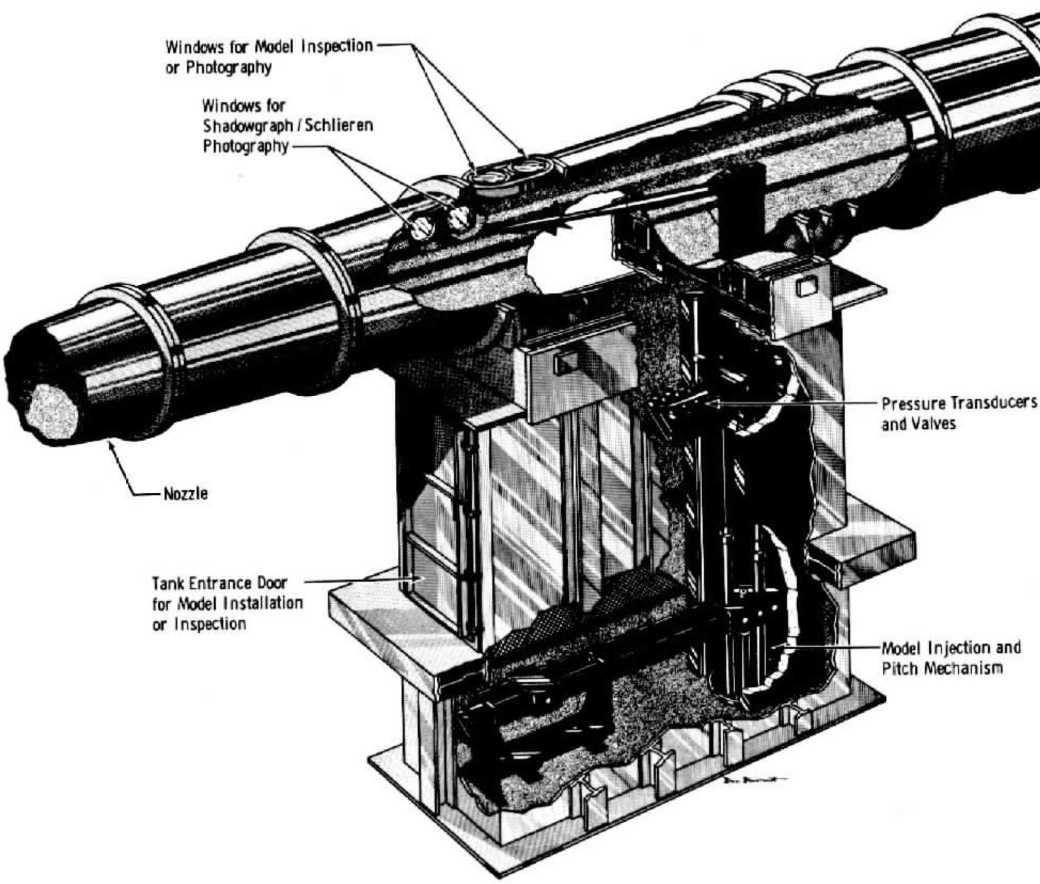
3. Varner, M. O. "Corrections to Single-Shielded Total Temperature Probes in Subsonic, Supersonic, and Hypersonic Flow," AEDC-TR-76-140, November 1976.

APPENDIX I

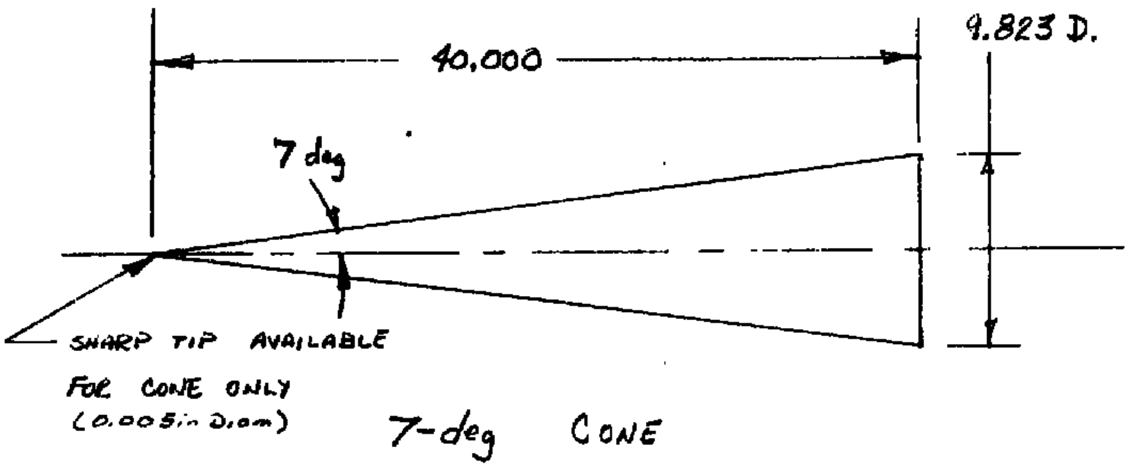
ILLUSTRATIONS



a. Tunnel assembly



b. Tunnel test section
Fig. 1. Tunnel B



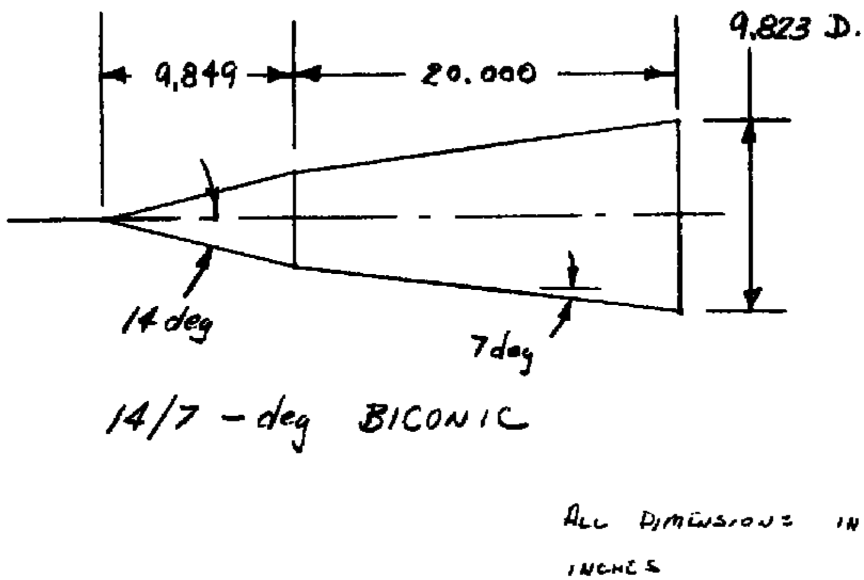
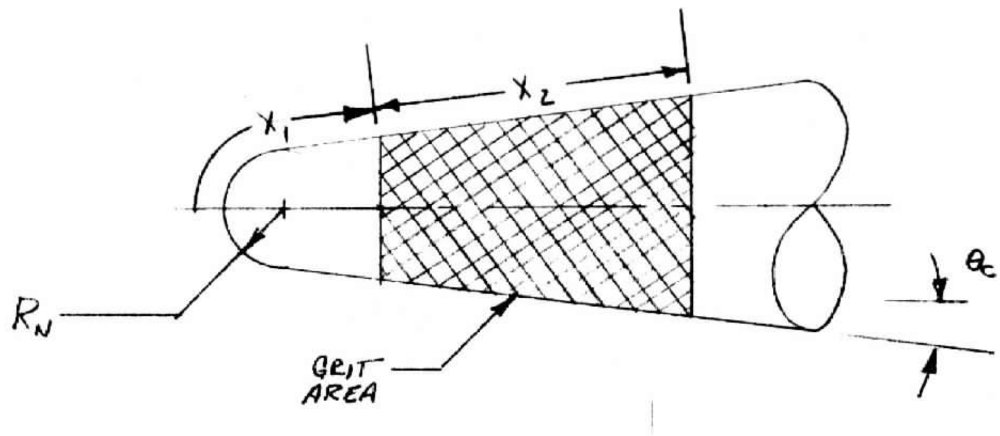


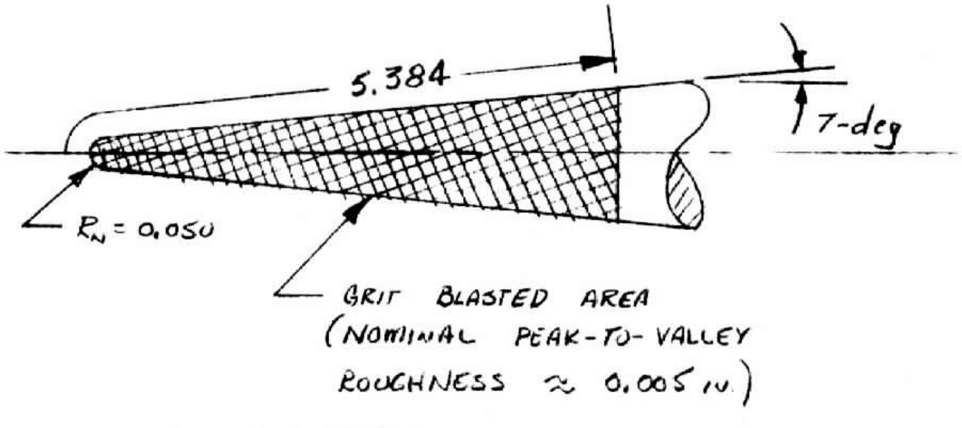
Fig. 2 Model Geometry



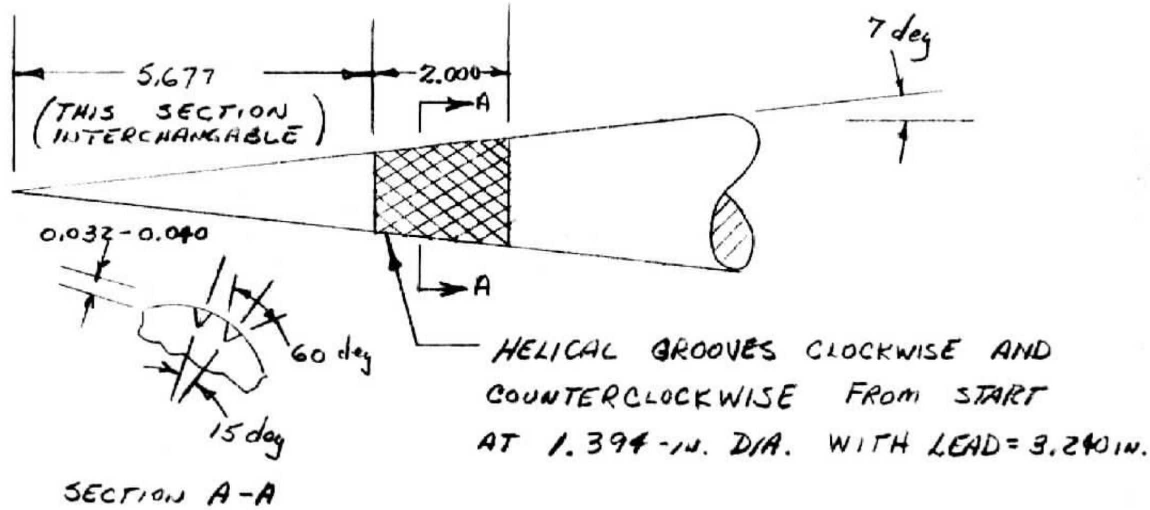
θc, IN	RN, IN	X1, IN	X2, IN	GRIT NO.	NOMINAL GRIT SIZE, IN
7	0.05	1.481	3.900	60	0.010
↓	↓	↓	↓	30	0.022
	0.10	1.552	3.500	46	0.014
	0.50	1.574	0.800	80	0.0065
	0.50	↓	↓	60	0.010
	0.50			30	0.022
	0.50			20	0.037
14	0.50	0.662	1.200	100	0.0048
↓	0.50	↓	↓	80	0.0065

a. Distributed grit trip

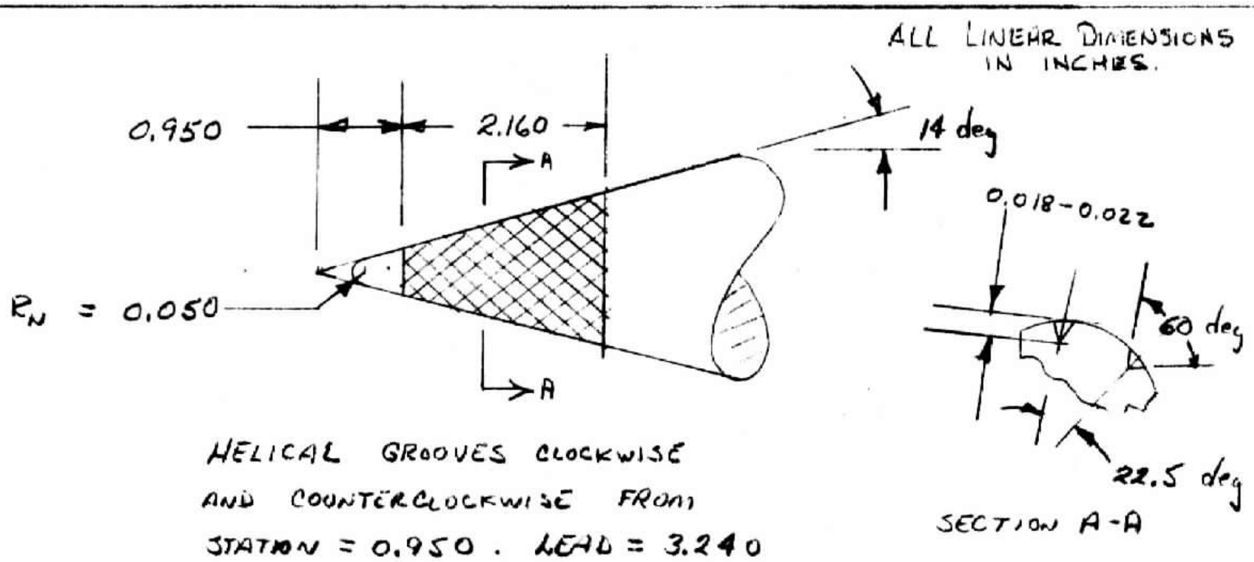
Fig. 3 Boundary-Layer Trip Geometry



b. 7-deg grit blasted nose

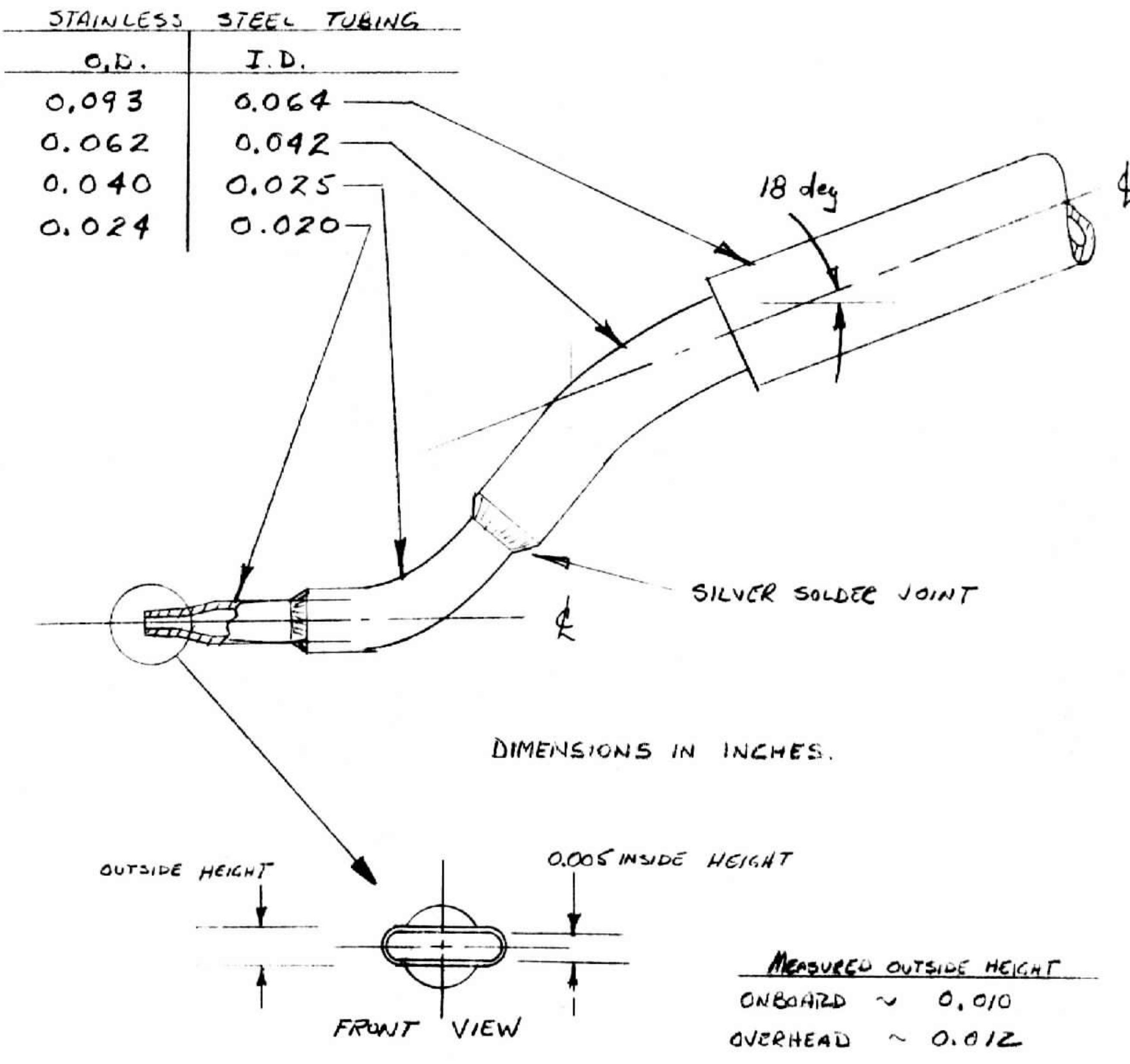


c. Grooved 7-deg insert



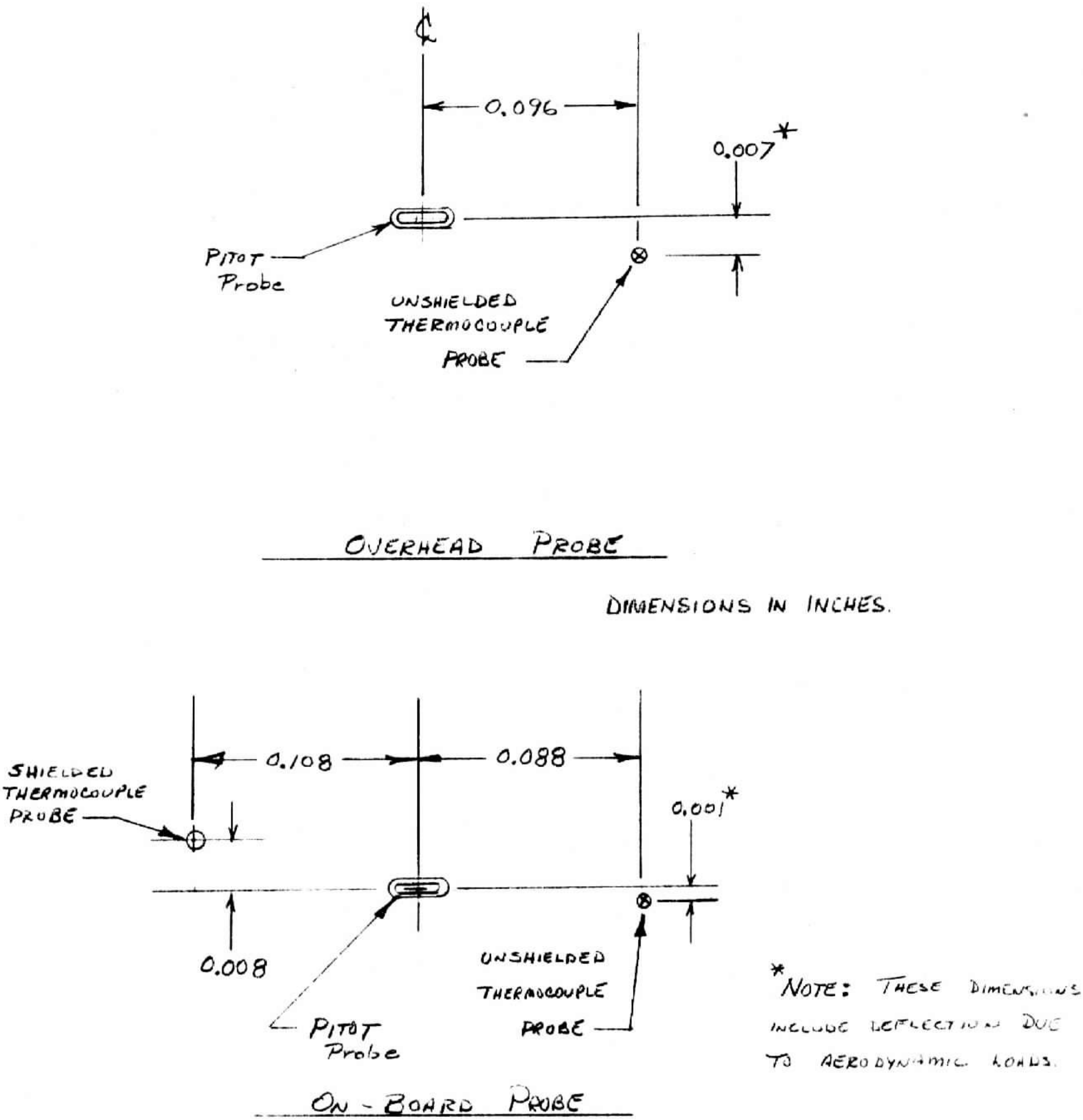
d. Grooved 14-deg nose

Fig. 3 Concluded



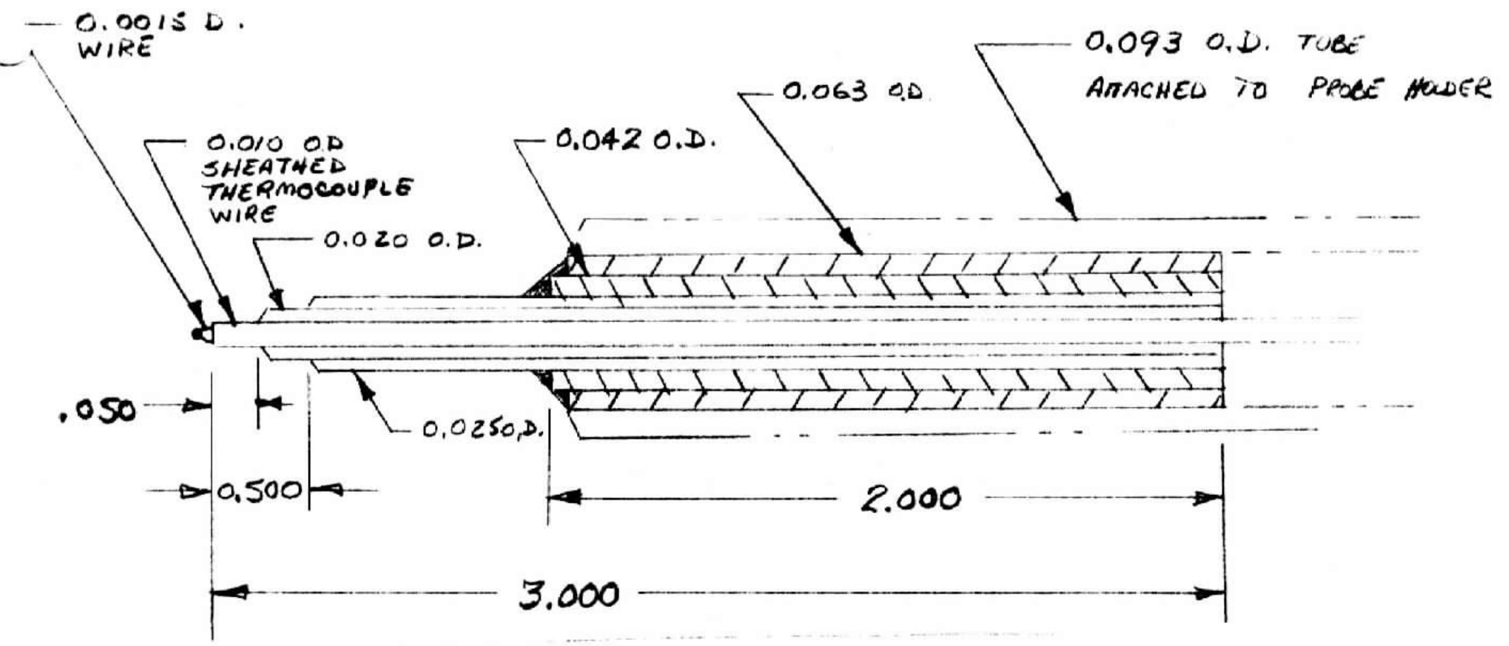
a. Pitot probe geometry

Fig. 4 Pitot Probe Geometry and Location

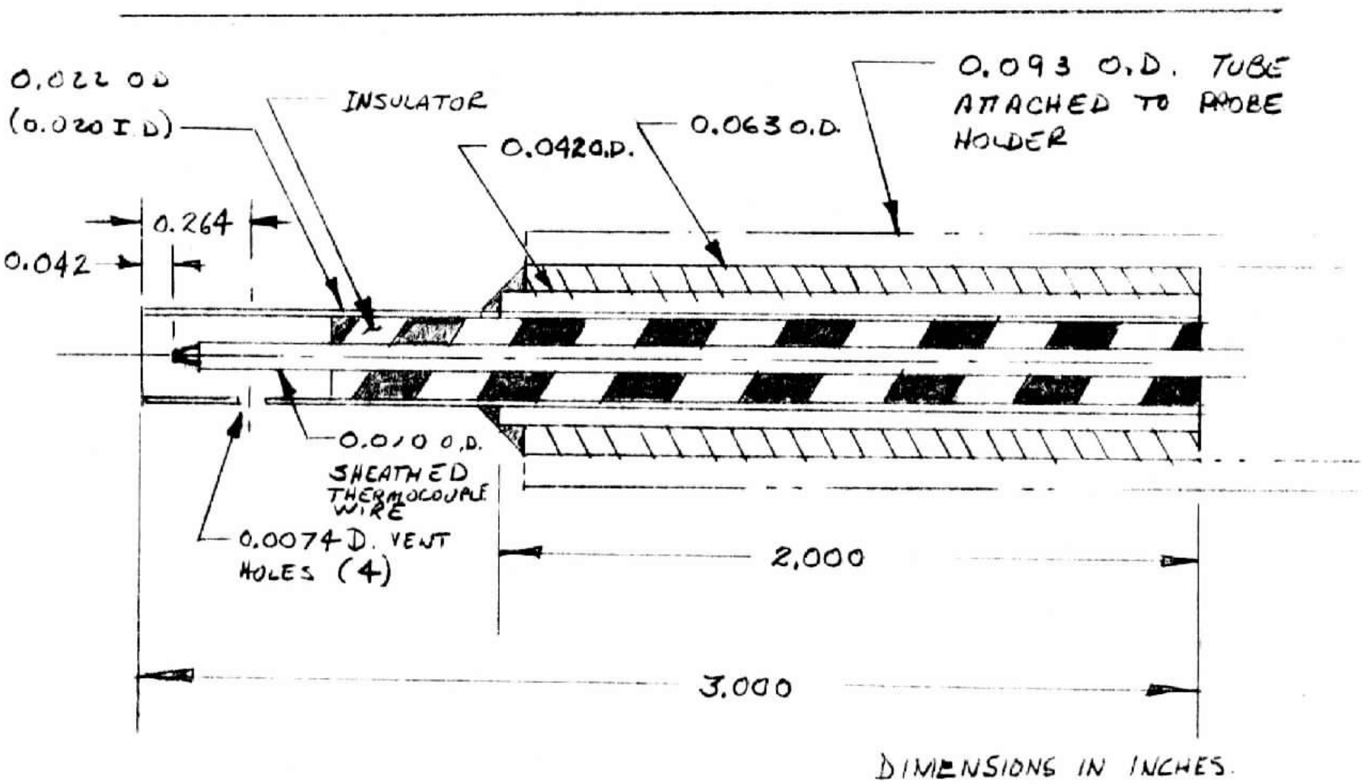


b. Pitot location relative to thermocouple probes

Fig. 4 Concluded



a. Unshielded thermocouple probe



b. Shielded thermocouple probe

Fig. 5 Total Temperature Probes

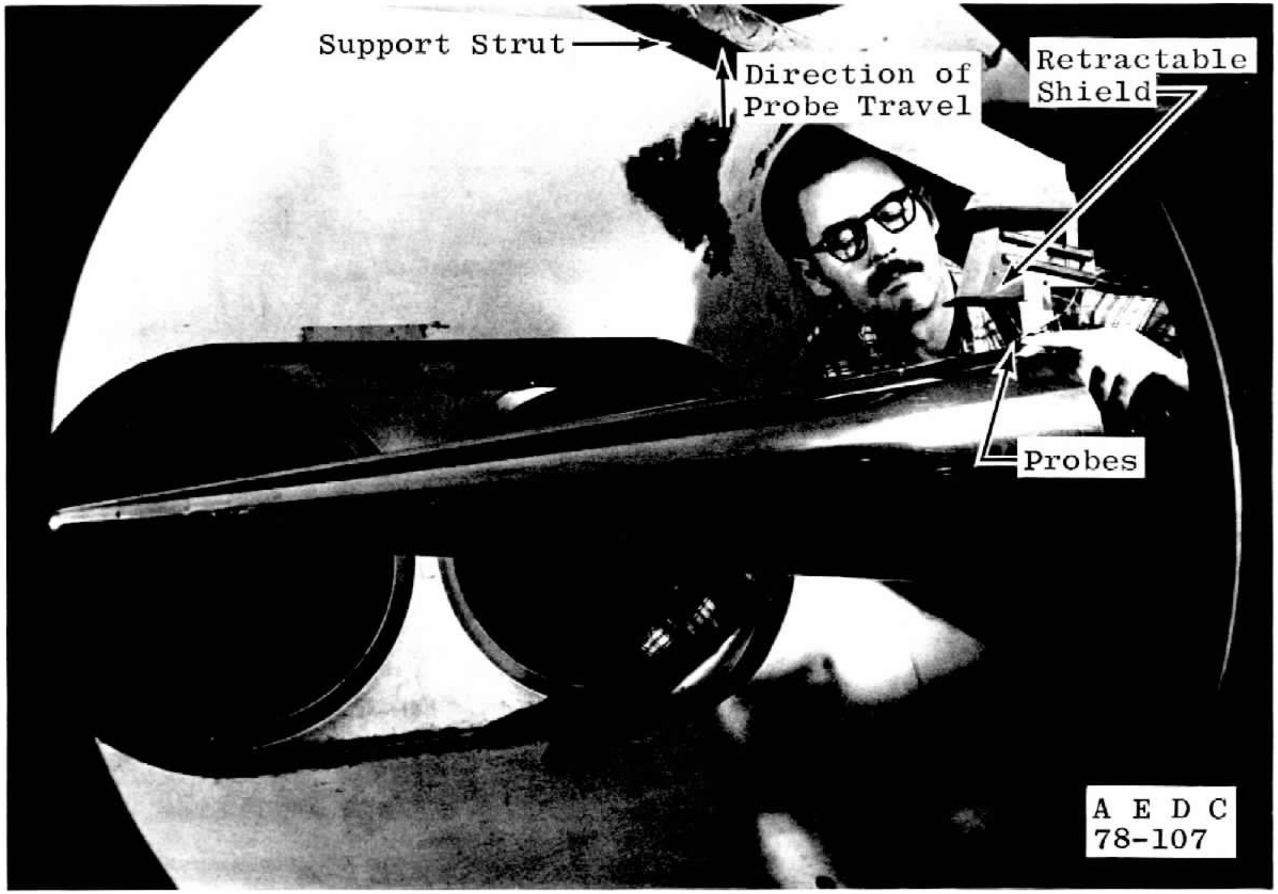
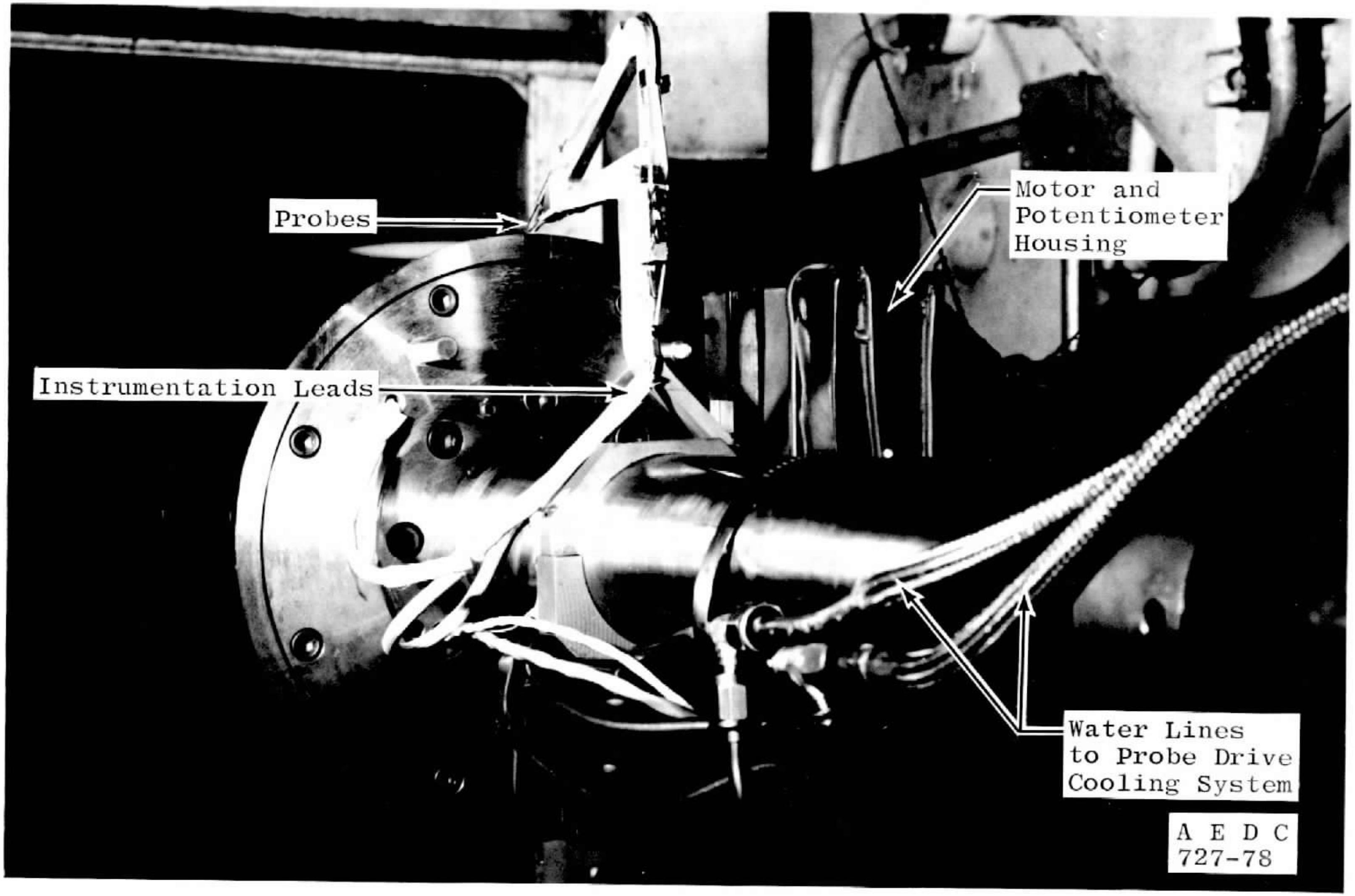
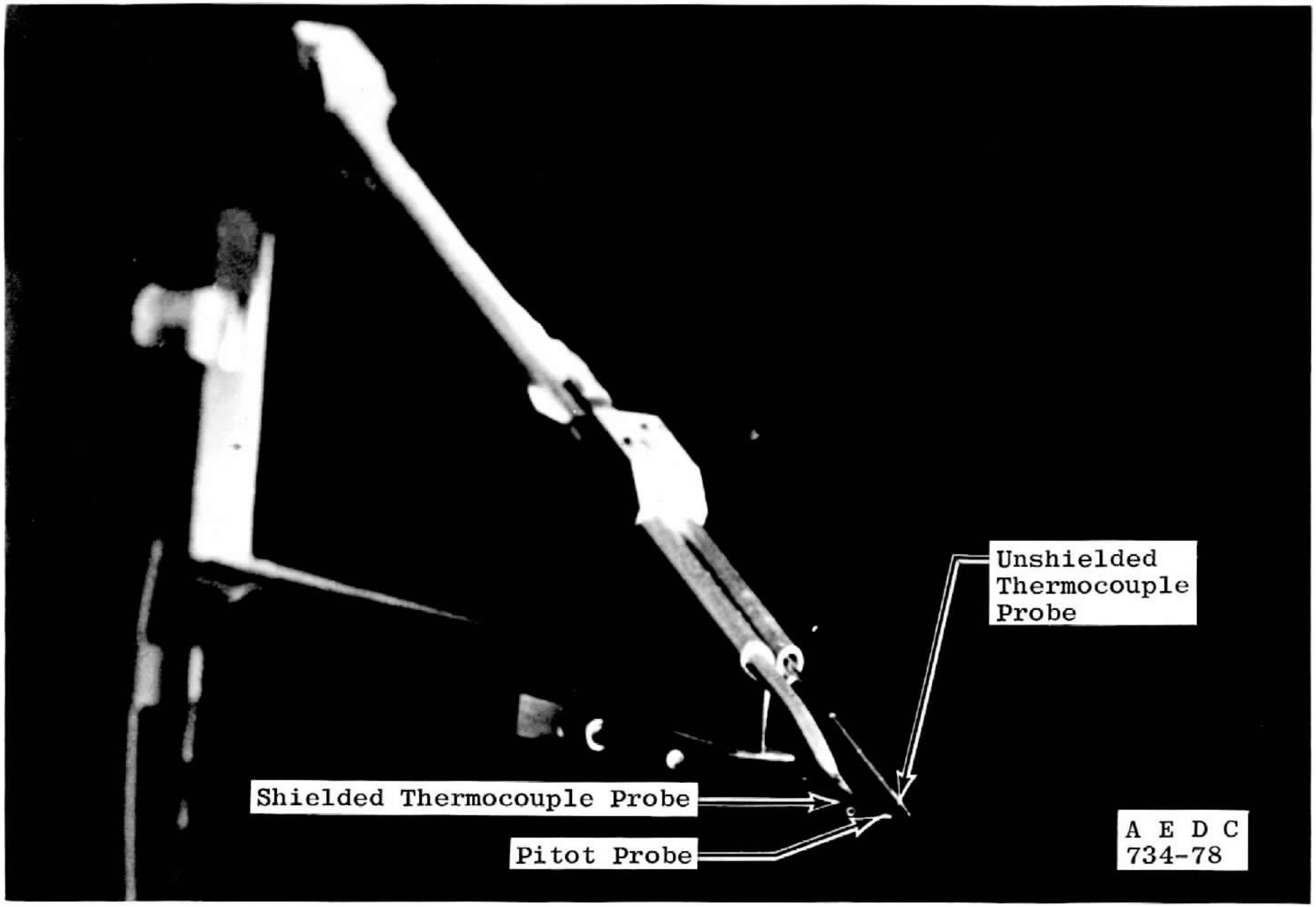


Fig. 6 Overhead Probe Installation



a. On-Board Probe Installation
Fig. 7 On-Board Probe



b. On-Board Probe Details
Figure 7 Concluded

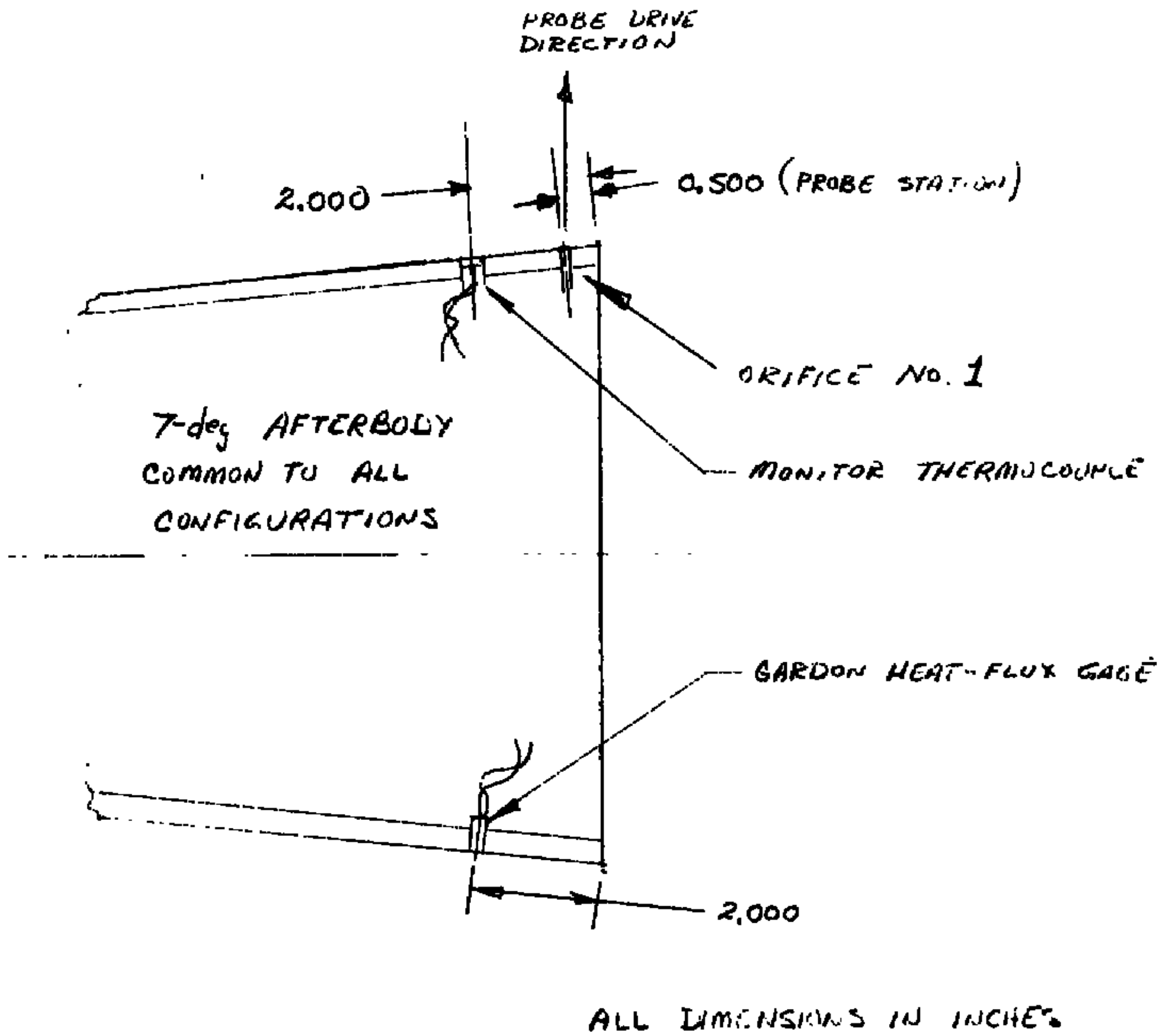


Fig. 8 Probe Survey Location and Related Wall Measurement Instrumentation

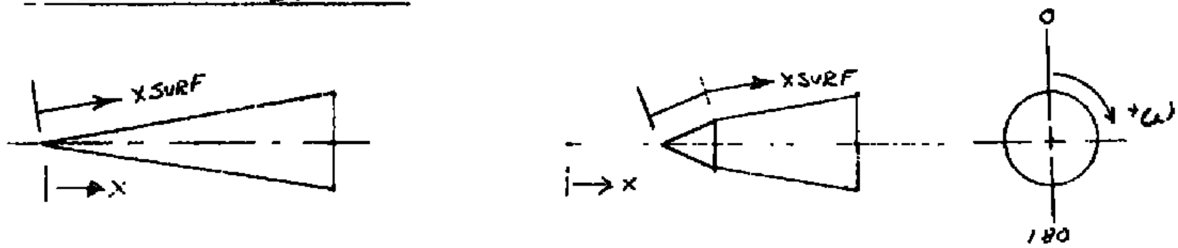
APPENDIX II

TABLES

TABLE 1

SURFACE INSTRUMENTATION LOCATIONS

A. PRESSURE ORIFICES

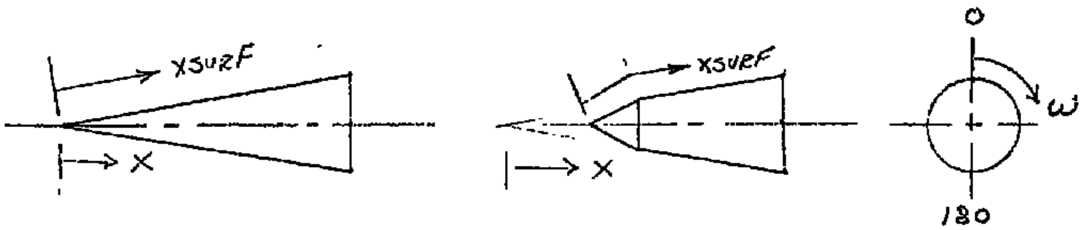


	XSURF, IN.		
ORIFICE NO.	7-deg CONE	14/7 BICONIC	ω, deg
1	39.800	29.801	0
2	38.300	28.301	
3	36.300	26.301	
4	34.300	24.301	
5	32.300	22.301	
6	30.300	20.301	
7	28.300	18.301	
8	26.300	16.301	
9	24.300	14.301	
10	22.300	12.301	
11	20.150	11.162	
12	17.150	10.787	
13	15.150	10.412	
14	13.150	9.909	
15	11.150	9.159	
16	9.150	7.159	
17	8.150	6.159	
18	—	5.159	
19	—	4.659	
20	—	4.159	
21	—	3.659	

TABLE 1. Continued

	XSURF, IN		
ORIFICE No.	7-deg CONE	14/7 BICONIC	ω, deg
22	39.800	29.801	-90
23	30.300	20.301	
24	11.150	4.659	
25	39.800	29.801	90
26	30.300	20.301	
27	11.150	4.659	
28	39.800	29.801	180
29	30.300	20.301	
30	11.150	4.659	
31	BASE	BASE	0
32	BASE	BASE	180
33	38.800	28.801	0

B. Heat Gages



	XSURF, IN		
GAGE NO.	7-deg CONE	14/7 BICONIC	ω, deg
1	38.300	28.301	180
2	36.300	26.301	
3	34.300	24.301	
4	32.240	22.241	
5	28.240	18.241	
6	26.240	16.241	
7	25.240	15.241	
8	24.240	14.241	
9	23.240	13.241	
10	22.240	12.241	
11	21.150	11.162	
12	20.150	10.787	
13	19.150	10.412	
14	18.150	9.909	
15	17.150	9.159	
16	15.150	7.159	
17	13.150	6.159	
18	9.150	5.159	
19	8.150	3.909	

TABLE 2

TEST CONDITIONS AND CONFIGURATIONS

GROUP	CONFIG	NOSE RADIUS	TRIP	$Re_\infty \times 10^{-6}$, FT^{-1}	α, deg	ϕ, deg	TYPE DATA
1	7-deg	SHARP	NONE	4.7	0	0	STATIC H.T.
2	CONE	SHARP	NONE		0	0	
3		0.500	NONE		0	0	
4		0.500			0	0	
5		0.500			0	90	
6		VOID					
7		0.500	0.014		0	0	
8		0.050	GRIT BLASTED		0	0	
9		0.050			0	90	
10		0.050	0.010		0	0	
11		0.500	0.0065		0	0	
12		0.500			0	90	
13		0.500			0	180	
14		SHARP	NONE		0	90	
15		SHARP			0	180	
16		0.100	0.014		0	0	
17		0.500	0.010		0	0	
18					-1 → 10	0	α SWEEP - H.T.
19					0	0 → 180	ROLL - H.T.
20					5	0 → 180	
21					10	0 → 180	
22		0.050	NONE		0	0	STATIC H.T.
23			GROOVES		0	0	
24		0.100	NONE		0	0	
25		0.500	0.010		0	0	ON-BOARD PROBE
26			NONE		0	0	
27			0.010		0	0	STATIC H.T.
28					0	180	
29		0.050			0	0	
30					0	180	

TABLE 2 Continued

GROUP	CONFIG.	NOSE RADIUS	TRIP	$Re_\infty \times 10^{-6}$, FT^{-1}	α, deg	ϕ, deg	TYPE DATA
31	7-deg	SHARP	NONE	4.7	0	0	SURF. PRESS.
32	CONE				0	180	
33					0	0	
34					0	0	ON-BOARD PROBE
35		VOID					
36		SHARP	NONE		0	0	OVERHEAD PROBE
37					0	0	STATIC-H.T. (HOT)
38		0.050	0.010		0	0	STATIC H.T.
39					0	180	
40		VOID					
41		0.500	0.010		0	0	SURF. PRESS.
42					0	0	ON-BOARD PROBE
43					0	0	STATIC H.T.
44		—	—	3.6	—	—	ON BOARD PROBE CALIB. POINT
45		—	—		—	—	OVERHEAD PROBE CALIB. POINT
46		—	—	2.5	—	—	
47		0.500	0.022		0	0	STATIC H.T.
48			NONE				
49		VOID					
50		VOID					
51		0.050	0.022	2.5	0	0	
52			NONE				
53							ON BOARD PROBE CALIB. POINT
54				1.6			
55							OVERHEAD PROBE CALIB. POINT
56		0.050		1.0			STATIC H.T.
57		0.500					
58		0.500	0.037				
59		0.050					
60		0.500	NONE				ON-BOARD PROBE
61		SHARP		4.7			SURF. PRESS.
62		0.500	0.010				
63		VOID					

TABLE 2 Concluded

GROUP	CONFIG	NOSE RADIUS	TRIP	$Re \times 10^{-6}$, FT^{-1}	α, deg	ϕ, deg	TYPE DATA
64	14/7	0.500	0.0065	4.7	0	0	STATIC H.T.
65	BICONIC			↓	0	180	↓
66	↓	0.050	NONE		0	0	
67					0	180	
68		0.050	GROOVES		0	0	
69					0	180	
70		0.500	NONE		0	0	
71		VOID					
72		0.500	0.0048		0	0	
73		↓	0.0065		↓		
74			↓		-1→14	0	α SWEEP - H.T.
75					↓	180	↓
76					0	0→180	ROLL - H.T.
77					↓		STATIC H.T.
78					-1→14	0	α SWEEP - H.T.
79					14	0→180	ROLL - H.T.
80					0	0	STATIC - H.T.
81					-1→14	180	α SWEEP - H.T.
82					0	0	SURF. PRESS.
83					↓	↓	↓
* 84							ON BOARD PROBE
85							OVERHEAD PROBE
86							STATIC H.T. (HOT)
87							OVERHEAD PROBE
88							OVERHEAD PROBE CALIB. POINT
89	—	—	—	1.0	—	—	↓
90	—	—	—	↓	—	—	ON-BOARD PROBE CALIB. POINT
91	14/7	0.500	0.0065	4.7	7	0→180	ROLL - H.T.

* PITOT. PROBE NOT FUNCTIONING.

TABLE 3

SHIELDED THERMOCOUPLE PROBE CORRECTION CONSTANTS

PEC	G
0	0
4	0.005
5	0.013
7	0.035
9	0.060
11	0.092
15	0.155
20	0.220
30	0.320
40	0.390
50	0.450
60	0.490
80	0.550
100	0.590
150	0.660
250	0.730
500	0.800
1000	0.860
10000	0.870

RED/(L/D)	U/UE
0	2.000
10.0	2.000
13.3	1.992
22.2	1.950
29.6	1.910
44.4	1.820
66.7	1.710
101.6	1.610
142.9	1.510
207.8	1.420
326.5	1.320
571.4	1.230
1142.9	1.160
2285.7	1.110
10000.0	1.050

APPENDIX III

DATA REDUCTION

DATA REDUCTION NOMENCLATURE

AE	Shielded thermocouple probe entrance area, in.^{2}
AN	Shielded thermocouple probe calibration constants
AV	Shielded thermocouple vent area, in.^{2}
C1	Gardon gage calibration factor at 70°F, BTU/ft^2 - sec - mv
C2	Gardon gage calibration factor at operating temperature, BTU/ft^2-sec-mv
CP	Specific heat of air, ft^2/sec^2-°R
DELU	Boundary-layer thickness, in.
DELU*	Boundary-layer displacement thickness, in.
DELU2	Boundary-layer momentum thickness, in.
DELU3	Boundary-layer kinetic energy thickness, in.
DELU4	Boundary-layer total enthalpy defect, in.
DS	Shield thermocouple probe inside diameter, ft
d	Unshielded thermocouple probe tip diameter, ft
E	Gardon gage output, mv
G	Shielded thermocouple probe calibration factor
H(TO)	Heat-transfer coefficient based on T_o, BTU ft^2 - sec-^{o}R
HU1	Shape factor, DELU*/DELU2
HU2	Shape factor, DELU2/DELU3
K	Gardon gage temperature calibration factor, °R/mv
LAMBDA	Shielded thermocouple calibration factor (see Eq. S-10)
L/D	Shielded thermocouple probe length-to-diameter ratio
ME	Shielded thermocouple probe entrance Mach number
MSI	Local Mach number at shielded temperature probe location
MUE	Flow viscosity at shielded thermocouple probe entrance, $\frac{\text{lbf sec}}{\text{FT}^2}$

MUI	Local Mach number at unshielded thermocouple probe location
MUUI	Local flow viscosity at the unshielded thermocouple probe location, lbf-sec/ft^2
M_∞	Free-stream Mach number
PEC	Peclet number
PO	Tunnel stilling chamber pressure, psia
POE	Local total pressure at the shielded thermocouple probe location, psf
POUI	Local total pressure at the unshielded thermocouple probe location, psia
PPS	Local pitot pressure at shielded thermcouple probe location, psia
PPU	Local pitot pressure at unshielded thermocouple probe location, psia
PR	Prandtl number = 0.715
PW1	Wall pressure at pressure orifice No. 1, psia
p_∞	Free-stream static pressure, psia
$\dot{q}$	Heat-flux rate, BTU/ft^2-sec
q_∞	Free-stream dynamic pressure, psia
R	Universal gas constant for air, ft^2/sec^2-°R
$\bar{R}$	Probe shield recovery factor = 0.84
RB	Body radius at probe station, in.
RED	Local entrance Reynolds number for the shielded thermocouple probe
REU	Local Reynolds number at unshielded thermocouple probe location
Re_∞, Re_∞/ft	Free-stream Reynolds number, ft^{-1}
RHOUE	Flow-field density at the boundary-layer edge, slugs/ft^3
RHOUI	Flow-field density at the unshielded thermocouple probe location, slugs/ft^3

ST(INF)	Stanton number
TCAL	Temperature parameter used to define boundary layer edge temperature (TED), °R
TE	Entrance static temperature for the shielded thermocouple probe, °R
TEDGE	Gardon gage sensing disc edge temperature, °R
TEU	Boundary-layer edge total temperature defined from corrected unshielded thermocouple probe data, °R
TO	Tunnel stilling chamber total temperature, °R
TOSI	Local corrected total temperature from shielded thermocouple probe, °R
TOUM	Measured total temperature from the unshielded thermocouple probe, °R
TOSM	Measured total temperature from the shielded thermocouple probe, °R
TSI	Local static temperature at the shielded thermocouple probe location, °R
TUI	Local static temperature at the unshielded thermocouple probe location, °R
TW	Model wall temperature, °R
ΔT	Temperature difference between the center and edge of a Gardon gage sensing disc, °R
U/UE	Velocity ratio at the entrance to shielded thermocouple probe, ft/sec
UUE	Boundary-layer edge velocity, ft/sec
UUI	Local velocity at unshielded thermocouple probe location, ft/sec
V_∞	Free-stream velocity, ft/sec
X, XSURF	Model station and surface length, respectively, in.
ZS	Height of shielded thermocouple probe above the model surface, in.
ZU	Height of unshielded thermocouple probe above the model surface, in.

γ	Ratio of specific heats = 1.4
η, ETA	Unshielded thermocouple probe calibration function

DATA REDUCTION

1. Surface Pressure Data

All surface pressure data were reduced using standard facility data reduction procedures. Linear transducer calibration factors were obtained prior to each operational period so a simple calculation was necessary:

PRESSURE = SCALE FACTOR (READING-ZERO) + REFERENCE

2. Heat-Transfer Data

Thermopile-type Gardon heat gages described in Ref. 1 were used to obtain heat-transfer distribution. The heat flux to the gage is computed as follows:

$$\dot{q} = C_2 E \tag{1}$$

where C_2 = gage calibration factor, $\frac{\text{BTU}}{\text{ft}^2\text{-sec-mv}}$

E = gage output, mv

Calibration factors include compensation for variation in wall temperature:

$$C_2 = C_1\Big[4.72878 - (2.83765 \times 10^{-2})\text{TEDGE} + (7.82707 \times 10^{-5})(\text{TEDGE})^2 - (9.44869 \times 10^{-8})(\text{TEDGE})^3 + (4.30151 \times 10^{-11})(\text{TEDGE})^4\Big] \tag{2}$$

where C_1 = gage calibration factor at 530°R

TEDGE = gage sensing disc edge temperatuare, °R

The temperature difference between the center and the edge of the sensing disc was calculated by:

$$\Delta T = K \cdot E \tag{3}$$

where:

K = gage temperature calibration factor, °R/mv

The gage edge temperature was measured directly and combined with ΔT to obtain an effective wall temperature:

$$T_w = TEDGE + 0.75\ \Delta T \tag{4}$$

This method of obtaining an effective wall temperature is discussed in detail in Ref. 2.

Heat-transfer coefficient was then calculated as:

$$H(TO) = \frac{\dot{q}}{TO-TW} \tag{5}$$

Further reduction to Stanton number was achieved using the following:

$$ST(INF) = \frac{H(TO)}{\rho_\infty V_\infty\ [0.2235 + (1.35 \times 10^{-5})(TO+TW)]} \tag{6}$$

3. Probe Data

Mean-flow boundary-layer data are presented as measured pressure and temperature values. Final reduced boundary-layer parameters are calculated only for those cases which satisfy the requirements for defining a boundary-layer edge. True probe heights above the cone surface were determined in the radial direction. The curvature of the model surface at the survey station, the lateral spacing of the probes in the rake, and the relative vertical spacing of the measurement probes were taken into account.

3.1 Pitot Pressures

Pitot pressure data were reduced following the procedures described in Section 1 which apply to surface pressure.

3.2 Shielded Thermocouple Measurements

The following calculation procedure was applied to obtain local total temperature from shielded thermocouple probe data following Varner's approach (Ref. 3) and is listed below and shown in a following block diagram.

S-1 Interpolate the local pitot pressure, PPO, from ZP to a value at the ZS locations. AT ZP = 0, set PPO = PW1. Designate interpolated values of PPO as PPS.

S-2 Compute the local Mach number, MSI, as follows:

a. If $PPS/PW1 \leq \left[\left((\gamma+1)/2\right)^{\frac{\gamma}{\gamma-1}}\right]$

b. Then $MSI = \left\{\left[\left(PPS/PW1\right)^{\frac{\gamma-1}{\gamma}} - 1\right]\left[2/(\gamma-1)\right]\right\}^{\frac{1}{2}}$

<u>Otherwise</u>, iterate the following to obtain MSI:

$$PPS/PW1 = \left[(\gamma+1)(MSI)^2/2\right]^{\frac{\gamma}{\gamma-1}} \cdot \left[(\gamma+1)/(2\gamma(MSI)^2-(\gamma-1))\right]^{\frac{1}{\gamma-1}}$$

S-3 $ME = 0.176$

S-4 $$TSI = \frac{TOSI}{1 + \frac{\gamma-1}{2}(MSI)^2}$$

S-5 $$TE = \frac{TOSI}{1 + \frac{\gamma-1}{2}(ME)^2}$$

For First Iteration, Set TOSI = TOSM

S-6 $$MUE = \frac{0.227(10^{-7})(TE)^{3/2}}{199 + TE}$$

S-7 If MSI < 1

$$POE = \left[PW1\left(1 + \frac{\gamma-1}{2}(MSI)^2\right)^{\frac{\gamma}{\gamma-1}}\right]144, \text{ psf}$$

If MSI $\geq$ 1

$$POE = \left\{PW1\left[\frac{(\gamma+1)(MSI)^2}{2}\right]^{\frac{\gamma}{\gamma-1}}\left[\frac{\gamma+1}{2\gamma(MSI)^2-(\gamma-1)}\right]^{\frac{1}{\gamma-1}}\right\}144, \text{ psf}$$

S-8 $$RED = \left[\left(\frac{2}{\gamma+1}\right)^{\frac{1}{\gamma-1}}\left(\frac{2\gamma}{\gamma+1}\right)^{1/2}\frac{1}{R^{1/2}}\right]\left(\frac{AV}{AE}\right)\left(\frac{POE}{MUE}\right)\left(\frac{DS}{(TOSI)^{1/2}}\right)$$

S-9 PEC = (RED)(PR/2) Note: Set PR = 0.715

S-10 $$LAMBDA = \Gamma = \left[\left(\frac{TE}{TSI}\right) - \left(1 + \frac{\gamma-1}{2}\bar{R}(MSI)^2\right)\right]\frac{TSI}{TOSI}$$

S-11 $$TOSI = TOSM\left\{1 + (G-1)\Gamma + \frac{\gamma}{2}\frac{R}{CP}\frac{TE}{TOSI}(ME)^2\left[\left(\frac{U}{UE}\right)^2 - 1\right]\right\}^{-1}$$

The values of G and U/UE are listed in Table 3.

INPUT DATA:

TOSM VS ZS
POE VS ZS
MSI VS ZS

At each ZS value, correct probe data as follows:

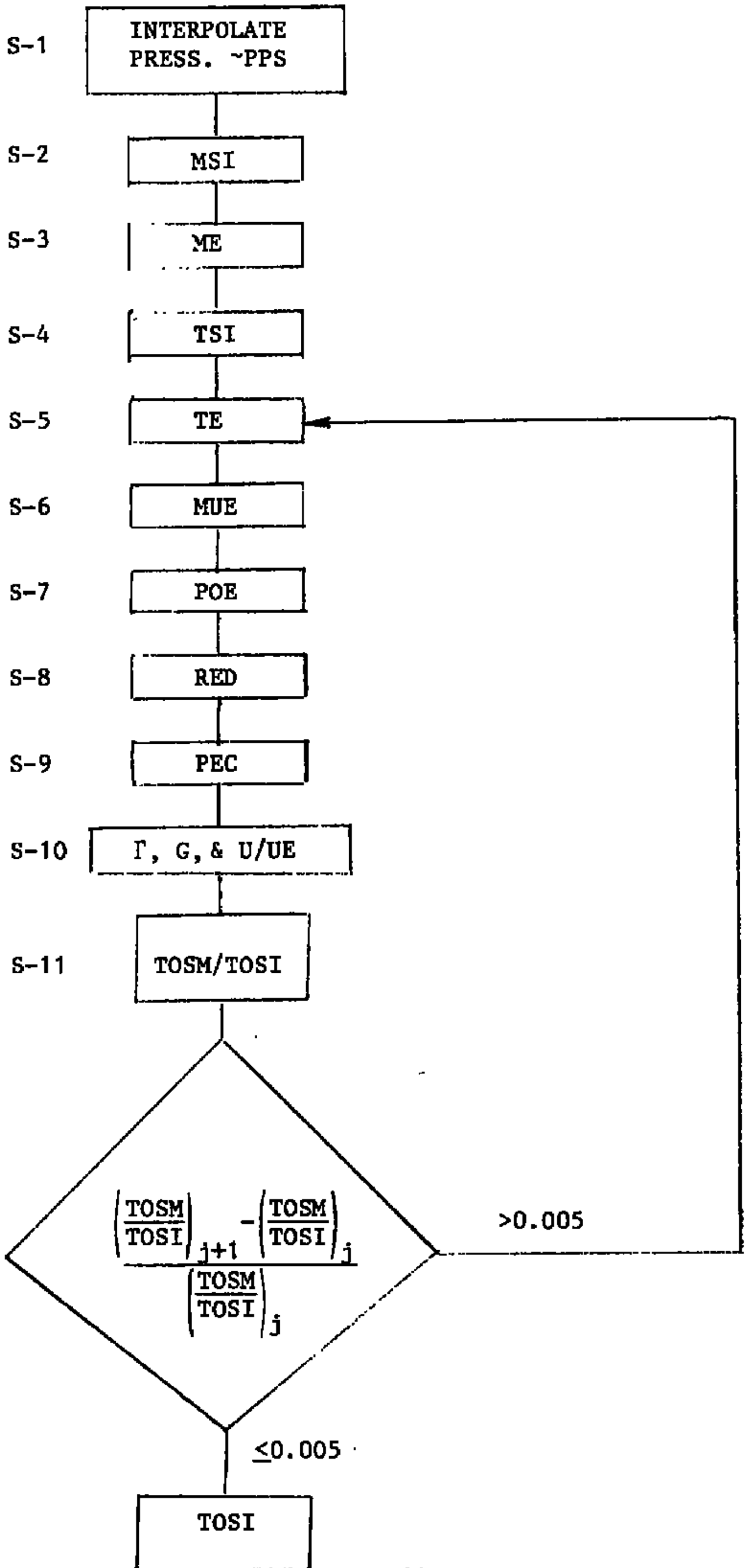
(a) Assume TOSI = TOSM compute Γ (Eq. S-10), RED (Eq. S-8), PEC (Eq. S-9).

(b) Compute G and U/UE by interpolating from Table 3

(c) Calculate the corrected temp., TOSI, from Eq. S-11

ON-BOARD SHIELDED THERMOCOUPLE PROBE CALCULATION

BLOCK DIAGRAM



(d) Using corrected value of TOSI, Repeat steps (a) through (c) until:

$$\frac{\left(\frac{TOSM}{TOSI}\right)_{j+1} - \left(\frac{TOSM}{TOSI}\right)_j}{\left(\frac{TOSM}{TOSI}\right)_j} \leq 0.0005$$

CONSTANT INPUTS:

γ = 1.4
R = Gas constant = 1717, ft^2/sec^2-°R
CP = 6006, ft^2/sec^2-°R
$\bar{R}$ = Probe shield recovery factor = 0.84
AV/AE = Vent area to entrance area ratio = 0.298
DS = Tube entrance inside diam = 0.001667 ft
L/D = Tube entrance length/diam ratio = 2.0

3.3 Unshielded Thermocouple Measurements

This section contains the procedure for obtaining local total temperature from the unshielded thermocouple probe output. The nomenclature used herein applies to the on-board probe although the identical procedure was used for the overhead probe. The procedure, shown in a block diagram (follows listing of equations) is as follows:

U-1 Interpolate the local pitot pressure, PPO, from ZP to a value at the ZU locations. Designate the interpolated values as PPU.

U-2 Compute the local Mach number, MUI, as follows:

a. If $PPU/PW1 \leq \left((\gamma+1)/2\right)^{\frac{\gamma}{\gamma-1}}$

b. Then $MUI = \left\{\left[\left(PPU/PW1\right)^{\frac{\gamma-1}{\gamma}} -1\right]\left[2/(\gamma-1)\right]\right\}^{1/2}$

<u>Otherwise</u>, iterate the following to obtain MUI:

c. $$PPU/PW1 = \left[(\gamma+1)(MUI)^2/2\right]^{\frac{\gamma}{\gamma-1}}\left[(\gamma+1)/2\gamma(MUI)^2-(\gamma-1)\right]^{\frac{1}{\gamma-1}}$$

U-3 If $MUI \leq 1$ POUI = PPU

If MUI > 1

$$POUI = PPU\left[\frac{(\gamma-1)(MUI)^2+2}{(\gamma+1)(MUI)^2}\right]^{\frac{\gamma}{\gamma-1}}\left[\frac{2\gamma(MUI)^2-(\gamma-1)}{\gamma+1}\right]^{\frac{1}{\gamma-1}}$$

U-4 $\quad RHOUI = \left(\frac{144\ PW1}{R\ TOUI}\right)\left[1 + \frac{\gamma-1}{2}(MUI)^2\right]$

U-5 $\quad TUI = TOUI\left(1 + \frac{(MUI)^2}{5}\right)^{-1}$

U-6 $\quad UUI = MUI\left[\gamma R(TUI)\right]^{1/2}$

U-7 $\quad MUUI = \frac{0.227(10^{-7})(TOUI)^{3/2}}{199 + TOUI}$

U-8 $\quad REU = \frac{(RHOUI)(UUI)(d)}{MUUI}$

U-9 $\quad \eta = ETA = \sum_{5=0}^{4} AN\left(\sqrt{REU}\right)^N$

Note that AN coefficients are unique for each probe

U-10 $\quad TOUI=TOUM\left[\frac{1 + \frac{\gamma-1}{2}(MUI)^2}{1 + \frac{\gamma-1}{2}\eta\,(MUI)^2}\right]$

INPUT DATA:

TOUM VS ZU
POUI VS ZU
MUI VS ZU

At each ZU value, the data was corrected as follows:

(a) Assume TOUI = TOUM, compute REU from Eq. U-8

(b) Compute η from Eq. U-9

(c) Compute corrected temperature, TOUI, from Eq. U-10

(d) Using the corrected value of TOUI, repeat steps (a) through (c) until

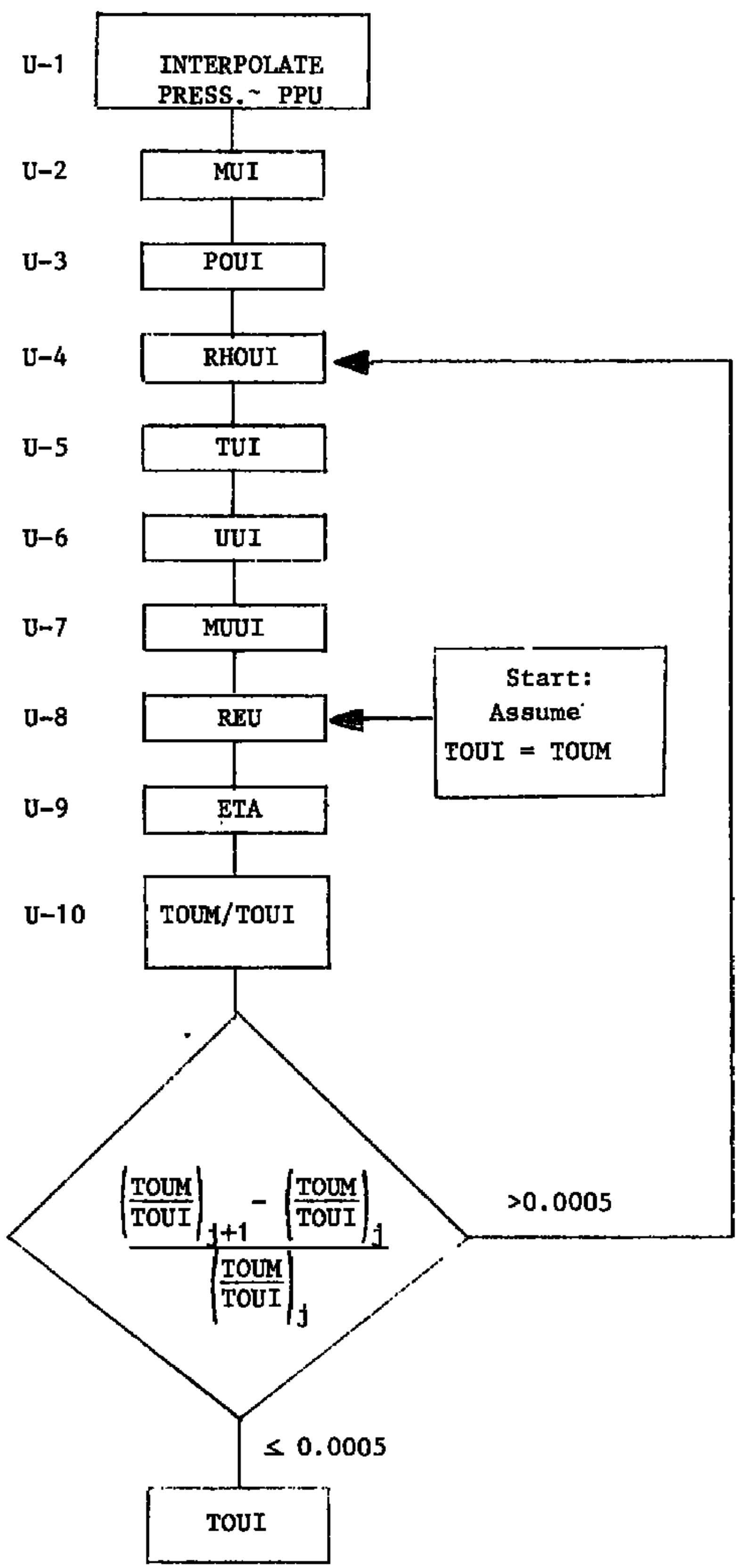
$$\frac{\left(\frac{TOUM}{TOUI}\right)_{j+1} - \left(\frac{TOUM}{TOUI}\right)_j}{\left(\frac{TOUM}{TOUI}\right)_j} \le 0.0005$$

INPUT CONSTANTS:

d - Probe tip diameter = 0.005 in. = 0.0004167 ft.
A0,A1,A2 .... Calibration constants (see Table 4)
γ = 1.4, ratio of specific heats

ON-BOARD UNSHIELDED THERMOCOUPLE CALCULATION

BLOCK DIAGRAM



4. Boundary-Layer Integral Values

The procedures described in this section were used to evaluate boundary-layer parameters from integral relationships. Establishment of the boundary-layer edge location and flow conditions is required to establish the upper limit for the integrals. Note the precaution listed with the calculations.

1. INPUT DATA:

   TOUI vs ZU

2. where TOUI is <u>corrected</u> unshielded thermocouple value.

3. Moving from the point ZU = 0.7 towards ZU = 0, curve fit the data set TOUI vs ZU. Sets of five points should be fitted with a second order (parabolic) fit.

4. Evaluate the curve fit segments and locate the value of ZU at which the value of

   TOUI = TCAL (1 ±0.0025).

   NOTE: For cases where TOUI = 0.9975 TCAL, print message:

   "BOUNDARY LAYER EDGE CONDITIONS OF TOTAL TEMPERATURE OVERSHOOT NOT MET. INTEGRAL PARAMETERS SHOULD BE USED WITH CAUTION."

5. When the point in Item 4 has been located evaluate both TOUI and ZU and designate as follows:

   DELU = ZU

   TEU = TOUI

6. INPUT DATA:

   RHOUI vs ZU (boundary-layer edge)

   UUI vs ZU

7. Using the same ZU values used in Item 4, fit the data from Item 6 with a second order (parabolic) fit.

8. Evaluate the curve fits in Item 7 at DELU = ZU. Designate the values of RHOUI and UUI as follows:

$$\left.\begin{array}{l} \text{RHOUI} = \text{RHOUE} \\ \text{UUI} = \text{UUE} \end{array}\right\} @ \text{ DELU}$$

9. Determine displacement thickness by evaluating the following:

$$\text{DELU*} + (\text{DELU*})^2 \frac{\cos\theta}{2\ (\text{RB})} = \int_{\text{ZU}=0}^{\text{DELU}} \left[1 - \frac{(\text{RHOUI})(\text{UUI})}{(\text{RHOUE})(\text{UUE})}\right]\left[1 + \frac{(\text{ZU})(\cos\theta)}{\text{RB}}\right] d\text{ZU}$$

where θ = body surface angle at the survey station, deg

RB = body radius at the survey station, in.

Use the quadratic equation:

$$\text{DELU*} = \frac{\sqrt{b^2-4ac} - b}{2a}$$

where

$$a = \frac{\cos\theta}{2(\text{RB})}$$

$$b = 1$$

$$c = -\int_{\text{ZU}=0}^{\text{DELU}} \left[1 - \frac{(\text{RHOUI})(\text{UUI})}{(\text{RHOUE})(\text{UUE})}\right]\left[1 + \frac{(\text{ZU})(\cos\theta)}{\text{RB}}\right] d\text{ZU}$$

10. Determine momentum thickness by evaluating the following:

$$\text{DELU2} + (\text{DELU2})^2 \frac{\cos\theta}{2\text{RB}} = \int_{\text{ZU}=0}^{\text{DELU}} \frac{(\text{RHOUI})(\text{UUI})}{(\text{RHOUE})(\text{UUE})}\left[1 - \frac{\text{UUI}}{\text{UUE}}\right]\left(1 + \frac{(\text{ZU})(\cos\theta)}{\text{RB}}\right) d\text{ZU}$$

Use the quadratic equation:

$$\text{DELU2}\ \frac{\sqrt{b^2-4ac}-b}{2a}$$

where

$$a = \frac{\cos\theta}{2\text{RB}}$$

$$b = 1$$

$$c = -\int_{\text{ZU}=0}^{\text{DELU}} \frac{(\text{RHOUI})(\text{UUI})}{(\text{RHOUE})(\text{UUE})}\left[1 - \frac{\text{UUI}}{\text{UUE}}\right]\left(1 + \frac{(\text{ZU})(\cos\theta)}{\text{RB}}\right) d\text{ZU}$$

11. Determine the kinetic energy defect from the following:

$$\text{DELU3} + (\text{DELU3})^3 \frac{\cos\theta}{2\text{RB}} = \int_{\text{ZU}=0}^{\text{DELU}} \frac{(\text{RHOUI})(\text{UUI})}{(\text{RHOUE})(\text{UUE})}\left[1 - \left(\frac{\text{UUI}}{\text{UUE}}\right)^2\right]\left(1 + \frac{(\text{ZU})(\cos\theta)}{\text{RB}}\right) d\text{ZU}$$

Use the quadratic equation:

$$\text{DELU3} = \frac{\sqrt{b^2-4ac}-b}{2a}$$

where

$$a = \frac{\cos\ \theta}{2RB}$$

$$b = 1$$

$$c = -\int_{ZU=0}^{DELU} \frac{(RHOUI)(UUI)}{(RHOUE)(UUE)}\left[1-\left(\frac{UUI}{UUE}\right)^2\right]\left(1 + \frac{(ZU)(\cos\ \theta)}{RB}\right)dZU$$

12. Determine the total enthalpy defect:

$$DELU4 + (DELU4)^2\ \frac{\cos\ \theta}{2RB} = \int_{ZU=0}^{DELU} \frac{(RHOUI)(UUI)}{(RHOUE)(UUE)}\left[1- \frac{TOUI}{TEU}\right]\left(1 + \frac{(ZU)(\cos\ \theta)}{RB}\right)dZU$$

Use the guadratic equation:

$$DELU4 = \frac{\sqrt{b^2-4ac} - b}{2a}$$

where

$$a = \frac{\cos\ \theta}{2RB}$$

$$b = 1$$

$$c = -\int_{ZU=0}^{DELU} \frac{(RHOUI)(UUI)}{(RHOUE)(UUE)}\left[1 - \frac{TOUI}{TEU}\right]\left(1 + \frac{(ZU)(\cos\ \theta)}{RB}\right)dZU$$

13. Calculate shape factor:

$$HU1 = \frac{DELU*}{DELU2}$$

$$HU2 = \frac{DELU2}{DELU3}$$

APPENDIX IV

SAMPLE DATA NOMENCLATURE AND FORMATS

1. Nomenclature: Surface Pressure Data
2. Sample Data: Surface Pressure Data
3. Nomenclature: Heat-Transfer Data
4. Sample Data: Heat-Transfer Data
5. Nomenclature: On-Board Probe Flow-Field Data
6. Sample Data: On-Board Probe Flow-Field Data
7. Nomenclature: Overhead Probe Flow-Field Data
8. Sample Data: Overhead Probe Flow-Field Data

IV-1. NOMENCLATURE: SURFACE PRESSURE DATA

ALPHA MODEL	Model angle of attack, deg
ALPHA PB	Support sting prebend angle, deg
CONFIGURATION	Model configuration (see Fig. 2)
DATA TYPE	Type of data tabulated
DEW POINT	Free-stream flow frost point, °F
GROUP	Data group number
L	Sharp 7-deg cone axial length, 40 in.
M(INF)	Free-stream Mach number
MU(INF)	Free-stream viscosity, lbf-sec/ft^2
NOSE RADIUS	Model nose tip radius, in.
ORIFICE	Model pressure ofifice identification (see Table 1)
PHI	Pressure orifice circumferential location (see Table 1), deg
P(INF)	Free-stream static pressure, psia
POP	Free-stream normal shock pressure, psia
PO	Tunnel stilling chamber pressure, psia
PW	Model wall pressure, psia
Q(INF)	Free-stream dynamic pressure, psia
RE(INF)	Free-stream Reynolds number, per foot
RHO(INF)	Free-stream density, slugs/ft^3
ROLL	Model roll angle, deg
T(INF)	Free-stream static temperature, °R
TO	Tunnel stilling chamber temperature, °R
TRIP	Boundary-layer trip configuration
U(INF)	Free-stream velocity, ft/sec
X	Model station, in.
XSURF	Orifice Surface location, in.

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ARNOLD AIR FORCE STATION, TENN

DATE COMPUTED 26-JUN-78
DATE RECORDED 30-JAN-78
TIME RECORDED 21: 3:55

PROJECT NO V41B-W6A
SAMSO/DOTR HYPERSONIC TURBULENT BOUNDARY LAYER INVESTIGATION
PHASE I

GROUP 31
M(INF)= 5.95
RE(INF)= 4.756E+06 PER FT

ALPHA MODEL = -0.35 DEG.
ALPHA PB = 13.00 DEG.
ROLL = -0.02 DEG.

DEW PT=-22.00 (DEG F)

CONFIGURATION 7-DEG CONE

NOSE RADIUS, IN SHARP

TRIP NONE

DATA TYPE
SURFACE PRES

ORIFICE	X (IN)	X/L	XSURF (IN)	PHI (DEG)	PW (PSIA)	PW/PINF
17	8.090	0.2023	8.150	0.	0.353	2.10
16	9.082	0.2271	9.150	0.	0.343	2.04
15	11.067	0.2767	11.150	0.	0.342	2.03
14	13.052	0.3263	13.150	0.	0.336	2.01
13	15.037	0.3759	15.150	0.	0.342	2.04
12	17.023	0.4256	17.150	0.	0.350	2.09
11	20.000	0.5000	20.150	0.	0.331	1.98
10	22.075	0.5519	22.300	0.	0.338	2.02
9	24.060	0.6015	24.300	0.	0.338	2.02
8	26.045	0.6511	26.300	0.	0.336	2.01
7	28.030	0.7008	28.300	0.	0.346	2.07
6	30.015	0.7504	30.300	0.	0.341	2.04
5	32.000	0.8000	32.300	0.	0.342	2.04
4	33.985	0.8496	34.300	0.	0.347	2.07
3	35.970	0.8993	36.300	0.	0.341	2.04
2	38.015	0.9504	38.300	0.	0.345	2.06
1	39.504	0.9876	39.800	0.	0.345	2.06
24	11.067	0.2767	11.150	-90.	0.323	1.92
23	30.015	0.7504	30.300	-90.	0.322	1.92
22	39.504	0.9876	39.800	-90.	0.323	1.92
27	11.067	0.2767	11.150	90.	0.324	1.93
26	30.015	0.7504	30.300	90.	0.323	1.92
25	39.504	0.9876	39.800	90.	0.330	1.96
30	11.067	0.2767	11.150	180.	0.323	1.93
29	30.015	0.7504	30.300	180.	0.304	1.81
28	39.504	0.9876	39.800	180.	0.315	1.88
33	38.511	0.9628	38.800	0.	0.345	2.06
31		BASE	BASE	0.	0.365	2.20
32		BASE	BASE	180.	0.082	0.49

PO = 250.73 PSIA
TO = 844.7 DEGR
P(INF)= 0.1672 PSIA
RE(INF)= 0.476E+07 PER FT
MU(INF)= 0.841E-07 LBF-SEC/FT2

U(INF)= 2982.2 FT/SEC
Q(INF)= 4.143 PSIA
T(INF)= 104.5 DEGR
POP = 7.70 PSIA
RHO(INF)= 0.134E-03 SLUGS/FT3

IV-2. Sample Data: Surface Pressure Data

IV-3. NOMENCLATURE: HEAT-TRANSFER DATA

ALPHA MODEL	Model angle of attack, deg
ALPHA PREBND	Support sting prebend angle, deg
ALPHA SECTOR	Tunnel sector pitch angle, deg
CONFIGURATION	Model configuration (see Fig. 2)
DATA TYPE	Type of data tabulated
DEW PT	Free-stream flow frost point, °F
GAGE NO.	Gardon gage identification number (see Table 1)
GROUP	Data group number
H(TO)	Heat-transfer coefficient, BTU/FT^2-sec-°R
L	Sharp 7-deg cone axial length, 40 in.
M(INF)	Free-stream Mach number
MODE	Static or dynamic data mode identification
MU(INF)	Free-stream viscosity, lbf-sec/ft^2
NOSE RADIUS	Model nose tip radius, in.
P(INF)	Free-stream static pressure, psia
PO	Tunnel stilling chamber pressure, psia
QDOT	Heat-flux rate, BTU/FT^2-sec
Q(INF)	Free-stream dynamic pressure, psia
RE(INF)	Free-stream Reynolds number, per ft
RHO(INF)	Free-stream density, lbm/ft^3
ROLL	Model roll angle, deg
ST(INF)	Stanton number
ST(INF)(CORRECTED)	Stanton number corrected (See Section 4.5)
TEDGE	Gardon gage sensing disc edge temperature, °R
T(INF)	Free-stream static temperature, °R
TO	Tunnel stilling chamber temperature, °R

TRIP	Boundary-layer trip configuration - sphere and grit sizes stated in inches
TW	Model wall temperature, °R
V(INF)	Free-stream velocity, ft/sec
X	Heat-gage model station, in.
XSURF	Heat-gage surface location (see Table 1), in.

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50 INCH HYPERSONIC TUNNEL B
ARNOLD AIR FORCE STATION, TN.
DATE 01/31/78 PROJECT NO. V41B-W6A

SAMSO/DOTR HYPERSONIC TURBULENT BOUNDARY LAYER INVESTIGATION
PHASE I
GARDON GAGES

DATE	TIME	TIME REDUCED	TIME FROM CL
01/23/78	21:15:22:369	21:15:42:372	1.04

DATA TYPE	CONFIGURATION	NOSE RADIUS, IN.	TRIP	MODE
HEAT TRANSFER	7-DEG CONE	SHARP	NONE	STATIC

GAGE NO.	X (IN.)	X/L	X SURFACE	QDOT (BTU/FT2-SEC)	TEDGE (DEG.R)	TW (DEG.R)	H(TO) (BTU/FT2-SEC-DEGR)	ST(INF)	ST(INF) (CORRECTED)
G19	8.090	.2023	8.150	0.3222	529.7	531.4	0.102E-02	0.326E-03	0.306E-03
G18	9.087	.2271	9.150	0.3636	529.7	531.6	0.115E-02	0.368E-03	0.353E-03
G17	13.052	.3263	13.150	0.9583	532.1	537.1	0.310E-02	0.988E-03	0.956E-03
G16	15.037	.3759	15.150	0.7589	532.1	536.1	0.244E-02	0.780E-03	0.780E-03
G15	17.023	.4256	17.150	0.9568	533.5	538.5	0.311E-02	0.991E-03	0.878E-03
G14	18.015	.4504	18.150	0.8594	532.8	537.3	0.278E-02	0.886E-03	0.958E-03
G13	19.008	.4752	19.150	0.7914	532.5	536.7	0.255E-02	0.815E-03	0.854E-03
G12	20.000	.5000	20.150	0.6903	533.1	536.7	0.223E-02	0.711E-03	0.829E-03
G11	20.993	.5248	21.150	0.7865	534.2	538.3	0.255E-02	0.814E-03	0.848E-03
G10	22.075	.5519	22.240	0.9432	532.9	537.8	0.305E-02	0.974E-03	0.833E-03
G9	23.067	.5767	23.240	0.9416	533.3	538.3	0.305E-02	0.974E-03	0.820E-03
G8	24.060	.6015	24.240	0.8512	533.9	538.3	0.276E-02	0.881E-03	0.820E-03
G7	25.052	.6263	25.240	0.8922	534.2	538.8	0.290E-02	0.925E-03	0.903E-03
G6	26.045	.6511	26.240	0.7296	534.4	538.3	0.237E-02	0.755E-03	0.803E-03
G5	28.030	.7008	28.240	0.7560	533.3	537.3	0.244E-02	0.780E-03	0.789E-03
G4	32.000	.8000	32.240	0.7770	532.6	536.7	0.251E-02	0.800E-03	0.713E-03
G3	33.985	.8496	34.300	0.7903	532.6	536.7	0.255E-02	0.814E-03	0.800E-03
G2	35.970	.8993	36.300	0.7618	528.8	532.8	0.243E-02	0.775E-03	0.807E-03
G1	38.015	.9504	38.300	0.8456	526.9	531.4	0.268E-02	0.856E-03	0.791E-03

M(INF)= 5.95
ROLL= -0.02 DEG.
ALPHA SECTOR= -13.06 DEG.
ALPHA PREBND= 13.00 DEG.
ALPHA MODEL = -0.06 DEG.

PO= 252.36 PSIA
TO= 846.7 DEG.R
P(INF)= .1683 PSIA
RE(INF)= 4.770E+06 PER FT.
MU(INF)= 8.432E-08LBF-SEC/FT2
RHO(INF)= 4.334E-03 LBM/FT3

V(INF)= 2965.7 FT/SEC
Q(INF)= 4.170 PSIA
T(INF)= 104.8 DEG.R
DEW PT= -20.DEG.F

GROUP 2

IV-4. Sample Data: Heat-Transfer Data

IV-5. NOMENCLATURE: ON-BOARD PROBE FLOW-FIELD DATA

PRINTOUT PAGE ONE

ALPHA MODEL	Model angle of attack, deg
ALPHA PB	Support sting prebend angle, deg
CONFIGURATION	Model configuration (see Fig. 2)
DATA TYPE	Type of data tabulated
DEW PT	Free-stream flow frost point, °F
GROUP	Data group number
LOOP	Data point identification number
M(INF)	Free-stream Mach number
MU(INF)	Free-stream viscosity, lbf-sec/ft^2
NOSE RADIUS	Model nose tip radius, in.
P(INF), PINF	Free-stream static pressure, psia
PO	Tunnel stilling chamber pressure, psia
POP	Free-stream total pressure downstream of a normal shock, psia
PPO	On-board probe pitot pressure, psia
PROBE STATION	Probe station location measured along model surface from model nose tip, in.
PWX	Model wall pressure at the survey station (X), psia
Q(INF)	Free-stream dynamic pressure, psia
RE(INF)	Free-stream Reynolds number, per foot
RHO(INF)	Free-stream density, slugs/ft^3
ROLL	Model roll angle, deg
T(INF)	Free-stream static temperature, °R
TGX	Surface temperature at model station (X), °R
TO	Tunnel stilling chamber temperature, °R
TOSM	Shielded thermocouple probe total temperature measurement, °R

TOUI,TOSI	Corrected total temperature measurement of the unshielded and shielded probes respectively, °R
TOUM	Unshielded thermocouple probe total temperature measurement, °R
TRIP	Boundary-layer trip configuration - sphere and grit dimensions stated in inches
TW1	Model wall temperature at probe survey station, °R
U(INF)	Free-stream velocity, ft/sec
UUI	Local velocity, ft/sec
ZP	Pitot probe height above model surface, in.
ZS	Height of shielded thermocouple probe above model surface, in.
ZU	Height of unshielded thermocouple probe above model surface, in.

PRINTOUT PAGE TWO

All heading information is identical to page one.

TG-1 - TG-19	Gardon gage case temperature, °R

PRINTOUT PAGE THREE (UNSHIELDED TEMPERATURE PROBE CORRECTIONS)

All heading information is identical to page one.

AO - A4	Calibration constants Effective probe recovery factor
ETA	
LOOP	Data point identification number
MUI	Local Mach number at survey point
PO	Tunnel stilling chamber pressure, psia
PPU	Local pitot pressure interpolated from
REU	Local Reynolds number at survey point
TO	Tunnel stilling chamber temperature, °R
TOUI	Local corrected total temperature at survey point, °R
TOUM	Unshielded thermocouple probe reading, °R
ZU	Height of unshielded thermocouple probe above model surface, in.

PRINTOUT PAGE FOUR (BOUNDARY LAYER VALUES)

DELU	Boundary-layer thickness, in.
DELU*	Displacement thickness, in.
DELU2	Momentum thickness, in.
DELU3	Kinetic energy defect, in.
DELU4	Total enthalpy defect, in.
HU1	Shape factor, DELU*/DELU2
HU2	Shape factor, DELU/DELU3
RHOUE	Flow density at boundary-layer edge, slugs/ft^3
TEU	Total temperature at boundary-layer edge, °R
UUE	Flow velocity at boundary-layer edge, ft/sec

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ARNOLD AIR FORCE STATION, TENN

DATE COMPUTED 8-JU..
DATE [redacted] 31-JA[redacted]
TIME RECORDED (1434

PROJECT NO (3-M6A
SAMSO/DOTR HYPERSONIC TURBULENT BOUNDARY LAYER INVESTIGATION
PHASE I

GROUP 42
M(INF)= 5.95
RE(INF)= 4.724E+06 PER FT

ALPHA MODEL = 0.06 DEG.
ALPHA PB = 13.00 DEG.
ROLL = -0.04 DEG.

DEW PT=-22.00 (DEG F)

CONFIGURATION 7-DEG CONE

NOSE RADIUS,IN .5000

TRIP .0100 GRIT

DATA TYPE
ON-BOARD PROBE

PROBE STATION = 36.45 IN.

LOOP	PO (PSIA)	TO (DEGR)	PINF (PSIA)	POP (PSIA)	ZP (IN)	PPO (PSIA)	PPO/POP	PW1 (PSIA)	TW1 (DEGR)	ZS (IN)	TOSM (DEGR)	TOSM/TO	ZU (IN)	TOUM (DEGR)	TOUM/TO
1	250.23	847.7	0.167	7.682	0.0050	0.587	0.076	0.386	704.	0.0142	760.	0.895	0.0048	731.	0.861
2	249.83	849.7	0.167	7.670	0.0160	0.830	0.108	0.399	708.	0.0252	767.	0.904	0.0158	743	.875
3	250.33	949.7	0.167	7.685	0.0245	1.510	0.196	0.412	713.	0.0337	770.	0.907	0.0243	753	.887
4	252.24	845.7	0.168	7.744	0.0345	1.936	0.252	0.400	716.	0.0437	769.	0.906	0.0343	757	.892
5	251.94	848.7	0.168	7.735	0.0450	2.148	0.279	0.386	718.	0.0542	770.	0.907	0.0448	760	.895
6	251.24	849.7	0.168	7.713	0.0545	2.301	0.299	0.373	722.	0.0637	774.	0.912	0.0543	762	.898
7	251.34	850.7	0.168	7.716	0.0640	2.455	0.319	0.361	724.	0.0732	777.	0.915	0.0638	764	.900
8	250.53	847.7	0.167	7.692	0.0735	2.608	0.339	0.351	725.	0.0827	779.	0.918	0.0733	766	.903
9	250.23	847.7	0.167	7.682	0.0850	2.776	0.361	0.343	726.	0.0942	782.	0.921	0.0848	768	.905
10	249.93	850.7	0.167	7.673	0.0965	2.930	0.381	0.336	727.	0.1057	784.	0.924	0.0963	769	.906
11	249.83	850.7	0.167	7.670	0.1045	3.098	0.403	0.332	728.	0.1137	786.	0.926	0.1043	770	.907
12	249.62	850.7	0.166	7.664	0.1270	3.391	0.441	0.327	729.	0.1362	790.	0.931	0.1268	773	.911
13	249.42	849.7	0.166	7.658	0.1480	3.824	0.497	0.325	730.	0.1572	793.	0.934	0.1478	775	.913
14	249.93	846.7	0.167	7.673	0.1655	4.136	0.537	0.324	731.	0.1747	794.	0.936	0.1653	777	.915
15	249.93	846.7	0.167	7.673	0.1850	4.614	0.599	0.325	732.	0.1942	796.	0.938	0.1848	779	.918
16	250.53	849.7	0.167	7.692	0.2045	5.056	0.657	0.325	733.	0.2137	798.	0.940	0.2043	781	.920
17	250.53	846.7	0.167	7.692	0.2245	5.527	0.718	0.325	734.	0.2336	801.	0.944	0.2243	782	.921
18	250.33	846.7	0.167	7.685	0.2450	6.055	0.787	0.326	734.	0.2541	803.	0.946	0.2448	783.	.923
19	251.03	849.7	0.167	7.707	0.2635	6.579	0.855	0.326	735.	0.2726	806.	0.950	0.2633	784.	.924
20	250.63	846.7	0.167	7.695	0.2970	7.253	0.942	0.327	736.	0.2961	809.	0.953	0.2868	784	.924
21	250.83	846.7	0.167	7.701	0.3065	7.891	1.024	0.327	737.	0.3156	812.	0.957	0.3063	783.	.923
22	250.93	846.7	0.167	7.704	0.3250	8.482	1.102	0.327	737.	0.3341	816.	0.961	0.3247	783.	.923
23	251.54	846.7	0.168	7.723	0.3455	9.166	1.191	0.327	738.	0.3546	819.	0.965	0.3452	782.	.921
24	251.34	849.7	0.168	7.716	0.3650	9.751	1.267	0.328	738.	0.3741	821.	0.967	0.3647	780.	.919
25	252.24	849.7	0.168	7.744	0.3855	10.299	1.338	0.328	739.	0.3946	823.	0.970	0.3852	778.	.917
26	252.14	849.7	0.168	7.741	0.4050	10.688	1.389	0.328	740.	0.4141	824.	0.971	0.4047	776.	.914
27	252.14	849.7	0.168	7.741	0.4240	10.978	1.427	0.328	740.	0.4331	824.	0.971	0.4237	775.	.913
28	251.44	849.7	0.168	7.719	0.4445	11.188	1.454	0.328	740.	0.4536	825.	0.972	0.4442	774.	.912
29	251.54	846.7	0.168	7.723	0.4660	11.336	1.473	0.327	740.	0.4751	825.	0.972	0.4657	774.	.912
30	251.44	846.7	0.168	7.719	0.4845	11.427	1.485	0.327	741.	0.4936	825.	0.972	0.4842	773.	.911
31	250.73	849.7	0.167	7.698	0.5055	11.647	1.513	0.327	741.	0.5146	825.	0.972	0.5052	773.	.911
32	250.83	846.7	0.167	7.701	0.6040	11.691	1.519	0.326	742.	0.6131	825.	0.972	0.6037	773.	.911

IV-6. Sample Data: On-Board Probe Flow-Field Data

LOOP	PO (PSIA)	TO (DEGR)	PINF (PSIA)	POP (PSIA)	ZP (IN)	PPO (PSIA)	PPO/POP	PW1 (PSIA)	TW1 (DEGR)	ZS (IN)	TOSM (DEGR)	TOSM/TO	ZU (IN)	TOUM (DEGR)	TOUM/TO
33	250.23	847.7	0.167	7.682	0.7040	11.754	1.527	0.326	742.	0.7130	825.	0.972	0.7037	773.	0.911
34	250.83	846.7	0.167	7.701	0.8055	11.780	1.531	0.325	742.	0.8145	825.	0.972	0.8052	772.	0.910
35	250.33	846.7	0.167	7.685	0.9050	11.783	1.531	0.326	743.	0.9140	825.	0.972	0.9047	773.	0.911
36	250.33	849.7	0.167	7.685	1.0060	11.788	1.532	0.326	743.	1.0150	825.	0.972	1.0057	772.	0.910
37	249.73	849.7	0.167	7.667	1.5055	11.737	1.525	0.325	743.	1.5144	825.	0.972	1.5051	772.	0.910
38	249.83	849.7	0.167	7.670	2.0035	11.440	1.486	0.325	744.	2.0124	824.	0.971	2.0031	772.	0.910
39	249.22	847.7	0.166	7.651	3.0030	10.743	1.396	0.325	744.	3.0117	823.	0.970	3.0025	772.	0.910
40	249.73	847.7	0.167	7.667	3.8850	9.617	1.250	0.324	744.	3.8937	822.	0.969	3.8944	771.	0.908

MEAN VALUES

PO = 250.67 PSIA	U(INF)= 2988.7 FT/SEC
TO = 848.4 DEGR	Q(INF)= 4.142 PSIA
P(INF)= 0.1671 PSIA	T(INF)= 105.0 DEGR
RE(INF)= 0.472E+07 PER FT	POP = 7.70 PSIA
MU(INF)= 0.845E-07 LBF-SEC/FT2	RHO(INF)= 0.134E-03 SLUGS/FT3

PROJECT NO V41( )A
SAMSO/DOTR HYPERSONIC TURBULENT BOUNDARY LAYER INVESTIGATION
PHASE I

GROUP 42
M(INF)= 5.95
RE(INF)= 4.724E+06 PER FT

ALPHA MODEL = 0.06 DEG.
ALPHA PB = 13.00 DEG.
ROLL = -0.04 DEG.

DEW PT=-22.00 (DEG F)

CONFIGURATION
7-DEG CONE

NOSE RADIUS, IN
.5000

TRIP
.0100 GRIT

DATA TYPE
ON-BOARD PROBE

PROBE STATION = 36.45 IN.

LOOP	TG-1 DEGR	TG-2 DEGR	TG-3 DEGR	TG-4 DEGR	TG-5 DEGR	TG-6 DEGR	TG-7 DEGR	TG-8 DEGR	TG-9 DEGR	TG-10 DEGR	TG-11 DEGR	TG-12 DEGR	TG-13 DEGR	TG-14 DEGR	TG-15 DEGR	TG-16 DEGR	TG-17 DEGR	TG-18 DEGR	TG-19 DEGR
1	704.	720.	721.	720.	728.	726.	723.	718.	712.	703.	702.	706.	707.	708.	707.	710.	695.	693.	696.
2	708.	724.	726.	725.	733.	730.	726.	722.	716.	708.	707.	710.	711.	712.	711.	714.	700.	699.	702.
3	713.	729.	731.	731.	737.	735.	731.	727.	721.	713.	712.	715.	715.	717.	716.	712.	706.	706.	709.
4	716.	732.	734.	735.	740.	738.	734.	730.	725.	718.	716.	719.	719.	720.	719.	749.	710.	710.	713.
5	718.	734.	736.	737.	743.	740.	736.	733.	728.	721.	719.	722.	721.	722.	722.	723.	713.	714.	716.
6	722.	737.	740.	742.	747.	745.	741.	737.	733.	726.	725.	727.	726.	727.	727.	723.	719.	720.	722.
7	724.	738.	741.	743.	748.	746.	742.	739.	734.	728.	726.	729.	728.	729.	728.	724.	721.	722.	724.
8	725.	739.	743.	745.	749.	747.	744.	740.	736.	730.	728.	730.	730.	730.	730.	726.	722.	723.	726.
9	726.	741.	744.	746.	750.	748.	745.	741.	738.	731.	730.	732.	731.	732.	731.	727.	724.	725.	727.
10	727.	741.	745.	747.	751.	749.	746.	743.	738.	732.	731.	733.	732.	733.	732.	729.	726.	727.	729.
11	728.	742.	746.	748.	752.	750.	747.	744.	740.	734.	733.	734.	734.	734.	734.	730.	727.	728.	730.
12	729.	743.	747.	749.	753.	751.	749.	745.	741.	735.	734.	735.	735.	735.	735.	731.	729.	730.	732.
13	730.	744.	748.	750.	754.	757.	748.	745.	742.	736.	735.	736.	736.	736.	736.	732.	730.	731.	732.
14	731.	745.	748.	751.	755.	753.	750.	747.	743.	738.	736.	738.	737.	737.	737.	734.	731.	732.	734.
15	732.	746.	749.	752.	756.	754.	751.	748.	745.	739.	738.	739.	738.	739.	738.	735.	733.	734.	735.
16	733.	746.	750.	753.	756.	755.	752.	749.	746.	740.	739.	740.	739.	740.	739.	736.	734.	735.	736.
17	734.	747.	751.	754.	757.	756.	753.	750.	747.	741.	740.	741.	740.	741.	740.	737.	735.	736.	737.
18	734.	747.	751.	754.	756.	756.	754.	750.	748.	742.	741.	742.	741.	742.	741.	738.	736.	737.	738.
19	735.	748.	752.	755.	758.	757.	754.	751.	748.	743.	742.	743.	742.	742.	742.	739.	737.	737.	739.
20	736.	749.	753.	756.	759.	758.	755.	753.	750.	745.	744.	745.	743.	744.	743.	740.	738.	739.	740.
21	737.	749.	753.	756.	760.	759.	756.	753.	751.	746.	744.	745.	744.	744.	744.	741.	739.	739.	741.
22	737.	750.	754.	757.	761.	759.	757.	754.	752.	747.	746.	746.	745.	745.	745.	742.	740.	740.	742.
23	738.	750.	754.	758.	761.	760.	758.	755.	753.	748.	747.	747.	746.	746.	746.	743.	741.	741.	742.
24	738.	750.	754.	758.	761.	761.	756.	756.	753.	749.	747.	748.	747.	747.	746.	744.	742.	742.	743.
25	739.	751.	755.	758.	762.	761.	759.	756.	754.	750.	748.	749.	748.	748.	747.	745.	742.	743.	744.
26	740.	751.	755.	759.	762.	762.	759.	757.	755.	751.	749.	750.	748.	748.	748.	745.	743.	743.	744.
27	740.	751.	755.	759.	762.	762.	759.	757.	756.	751.	750.	750.	749.	749.	748.	746.	744.	744.	745.
28	740.	752.	756.	759.	763.	762.	760.	758.	756.	752.	750.	751.	749.	749.	749.	746.	744.	744.	745.
29	740.	752.	756.	759.	763.	762.	760.	758.	756.	752.	751.	751.	750.	750.	749.	747.	745.	744.	746.
30	741.	752.	756.	760.	763.	763.	761.	759.	757.	753.	752.	752.	751.	751.	750.	748.	745.	745.	746.
31	741.	753.	756.	760.	764.	763.	761.	759.	758.	753.	752.	752.	751.	751.	750.	748.	746.	746.	747.
32	742.	753.	757.	760.	764.	764.	761.	760.	758.	754.	753.	753.	752.	751.	751.	748.	746.	746.	747.
33	742.	753.	757.	761.	764.	764.	762.	760.	758.	754.	753.	753.	752.	752.	751.	749.	747.	746.	747.
34	742.	753.	757.	761.	765.	764.	762.	760.	759.	755.	754.	754.	753.	752.	752.	749.	747.	747.	748.
35	743.	754.	757.	761.	765.	765.	762.	761.	759.	755.	754.	754.	753.	753.	752.	750.	748.	747.	748.
36	743.	754.	758.	761.	765.	765.	763.	761.	759.	756.	755.	755.	753.	753.	753.	750.	748.	748.	748.
37	743.	754.	758.	762.	765.	765.	763.	762.	760.	756.	755.	755.	754.	754.	753.	751.	749.	748.	749.
38	744.	754.	758.	762.	766.	766.	764.	762.	761.	757.	756.	756.	754.	754.	754.	751.	749.	748.	749.
39	744.	755.	758.	762.	766.	766.	764.	762.	761.	757.	756.	756.	755.	755.	754.	752.	750.	749.	750.
40	744.	755.	759.	762.	766.	766.	764.	763.	761.	758.	757.	757.	755.	755.	754.	752.	750.	749.	750.

ARO, INC - AEDC DIVISION
A SVERDRUP CORPORATION COMPANY
VON KARMAN GAS DYNAMICS FACILITY
ARNOLD AIR FORCE STATION, TENN

DATE C[illegible]TED [illegible]-JU[illegible]
DATE RECORDED 3/ JAN-78
TIME RECORDED .51 9

PROJECT NO V41B-K6A
SAMSO/DOTR HYPERSONIC TURBULENT BOUNDARY LAYER INVESTIGATION
PHASE I

GROUP 42
M(INF)= 5.95
RE(INF)= 4.724E+06 PER FT

ALPHA MODEL = 0.06 DEG.
ALPHA PB = 13.00 DEG.
ROLL = -0.04 DEG.

DEW PT=-22.00 (DEG F)

CONFIGURATION
7-DEG CONE

NOSE RADIUS, IN
.5000

TRIP
.0100 GRIT

UNSHIELDED TEMPERATURE PROBE CORRECTIONS
ON-BOARD PROBE

PROBE STATION = 36.45 IN.

LOOP	ZU (IN)	PO (PSIA)	TO (DEGR)	PPU (PSIA)	PPU/PO	MUI	REU	ETA	TOUM/TO	TOUI (DEGR)	TOUI/TO	UUI (FT/SEC)
1	0.0048	250.23	847.7	0.576	0.0023	0.95	42.70	0.874	0.861	745.	0.878	1165.05
2	0.0158	249.83	849.7	0.826	0.0033	1.24	57.31	0.875	0.875	765.	0.902	1473.90
3	0.0243	250.33	849.7	1.493	0.0060	1.78	88.45	0.878	0.887	790.	0.931	1922.21
4	0.0343	252.24	845.7	1.927	0.0077	2.06	106.48	0.879	0.892	801.	0.944	2100.25
5	0.0443	251.94	848.7	2.144	0.0086	2.18	115.50	0.880	0.495	807.	0.951	2173.88
6	0.0543	251.24	849.7	2.297	0.0092	2.26	120.91	0.880	0.898	811.	0.956	2220.42
7	0.0633	251.34	850.7	2.451	0.0096	2.34	126.81	0.880	0.900	815.	0.960	2263.89
8	0.0733	250.53	847.7	2.604	0.0104	2.42	132.52	0.881	0.903	818.	0.965	2303.51
9	0.0848	250.23	847.7	2.772	0.0111	2.50	138.77	0.881	0.905	822.	0.969	2343.68
10	0.0963	249.93	850.7	2.927	0.0117	2.57	144.63	0.881	0.906	824.	0.972	2376.69
11	0.1043	249.83	850.7	3.093	0.0123	2.65	150.98	0.892	0.907	827.	0.975	2409.94
12	0.1268	249.62	850.7	3.388	0.0135	2.78	161.71	0.882	0.911	832.	0.981	2464.90
13	0.1478	249.42	849.7	3.820	0.0152	2.96	177.80	0.883	0.913	837.	0.987	2531.22
14	0.1653	249.93	846.7	4.132	0.0165	3.09	189.22	0.884	0.915	841.	0.991	2574.12
15	0.1848	249.93	846.7	4.608	0.0184	3.27	206.67	0.885	0.918	845.	0.996	2629.55
16	0.2043	250.53	849.7	5.051	0.0202	3.42	222.72	0.885	0.920	849.	1.001	2674.41
17	0.2243	250.53	846.7	5.521	0.0220	3.59	240.09	0.886	0.921	851.	1.004	2714.38
18	0.2448	250.33	846.7	6.049	0.0241	3.76	259.46	0.887	0.923	854.	1.007	2753.03
19	0.2633	251.03	849.7	6.572	0.0262	3.92	279.57	0.888	0.924	856.	1.009	2786.46
20	0.2868	250.63	846.7	7.246	0.0289	4.12	303.73	0.889	0.924	857.	1.011	2821.48
21	0.3063	250.83	846.7	7.873	0.0314	4.30	327.70	0.890	0.923	857.	1.010	2847.57
22	0.3247	250.93	846.7	8.474	0.0338	4.46	350.18	0.891	0.923	858.	1.011	2870.80
23	0.3452	251.54	846.7	9.158	0.0365	4.64	376.32	0.891	0.921	857.	1.010	2892.00
24	0.3647	251.34	849.7	9.743	0.0389	4.79	399.50	0.892	0.919	855.	1.008	2905.61
25	0.3852	252.24	849.7	10.292	0.0411	4.93	421.56	0.893	0.917	853.	1.006	2916.50
26	0.4047	252.14	849.7	10.683	0.0426	5.02	437.69	0.894	0.914	851.	1.003	2922.22
27	0.4237	252.14	849.7	10.974	0.0438	5.09	449.43	0.894	0.913	850.	1.002	2926.98
28	0.4442	251.44	849.7	11.185	0.0446	5.14	458.14	0.894	0.912	849.	1.001	2929.68
29	0.4657	251.54	846.7	11.334	0.0452	5.18	463.81	0.894	0.912	849.	1.001	2932.44
30	0.4842	251.44	846.7	11.426	0.0456	5.20	468.05	0.894	0.911	848.	1.000	2932.84
31	0.5052	250.73	849.7	11.644	0.0465	5.25	476.37	0.895	0.911	848.	1.000	2937.27
32	0.5037	250.83	846.7	11.691	0.0466	5.26	478.17	0.895	0.911	848.	1.000	2938.20

LOOP	ZU (IN)	PO (PSIA)	TO (DEGR)	PPU (PSIA)	PPU/PO	MUI	REU	ETA	TOUM/TO	TOUI (DEGR)	TOUI/TO	UUI (FT/SEC)
33	0.7037	250.23	847.7	11.754	0.0469	5.27	480.55	0.895	0.911	848.	1.000	2939.43
34	0.8052	250.83	846.7	11.780	0.0470	5.28	482.30	0.895	0.910	847.	0.995	2938.01
35	0.9047	250.33	846.7	11.783	0.0470	5.28	481.66	0.895	0.911	848.	1.000	2940.00
36	1.0057	250.33	849.7	11.788	0.0470	5.28	482.59	0.895	0.910	847.	0.999	2938.16
37	1.5051	249.73	849.7	11.737	0.0468	5.27	480.67	0.895	0.910	847.	0.999	2937.17
38	2.0031	249.83	849.7	11.440	0.0456	5.20	469.31	0.895	0.910	847.	0.998	2931.19
39	3.0025	249.22	847.7	10.744	0.0429	5.04	442.74	0.894	0.910	847.	0.998	2915.97
40	3.8844	249.73	847.7	9.617	0.0384	4.76	400.33	0.892	0.908	845.	0.996	2884.99

CALIBRATION CONSTANTS
A0= 8.650E-01 A1= 1.363E-03 A2= 0.000E+00 A3= 0.000E+00 A4= 0.000E+00

MEAN VALUES

PO = 250.67 PSIA	U(INF)= 2988.7 FT/SEC
TO = 848.4 DEGR	Q(INF)= 4.142 PSIA
P(INF)= 0.1671 PSIA	T(INF)= 105.0 DEGR
RE(INF)= 0.472E+07 PER FT	POP = 7.70 PSIA
MU(INF)= 0.845E-07 LBF-SEC/FT2	RHO(INF)= 0.134E-03 SLUGS/FT3

PROJECT NO V41B-W6A
SAMSO/DOTR HYPERSONIC TURBULENT BOUNDARY LAYER INVESTIGATION
PHASE I

GROUP 42
M(INF)= 5.95
RE(INF)= 4.724E+06 PER FT

ALPHA MODEL = 0.06 DEG.
ALPHA PB = 13.00 DEG.
ROLL = -0.04 DEG.

DEW PT=-22.00 (DEG F)

CONFIGURATION 7-DEG CONE

NOSE RADIUS,IN .5000

TRIP .0100 GRIT

DATA TYPE
ON-BOARD PROBE

PROBE STATION = 36.45 IN.

BOUNDARY LAYER VALUES

DELU = 0.4267 IN.
DELU*= 0.1955 IN.
DELU2= 0.0159 IN.
DELU3= 0.0291 IN.
DELU4= 0.0008 IN.
HU1 = 12.2798
HU2 = 0.5475
TEU = 850.4 DEGR
UUE = 2927.3 FT PER SECOND
RHOUE= 1.981E-04 SLUGS PER FT3

MEAN VALUES

PO = 250.67 PSIA
TO = 848.4 DEGR
P(INF)= 0.1671 PSIA
RE(INF)= 0.472E+07 PER FT
MU(INF)= 0.845E-07 LBF-SEC/FT2

U(INF)= 2988.7 FT/SEC
Q(INF)= 4.142 PSIA
T(INF)= 105.0 DEGR
POP = 7.70 PSIA
RHO(INF)= 0.134E-03 SLUGS/FT3

IV-7. NOMENCLATURE: OVERHEAD PROBE FLOW-FIELD DATA

PRINTOUT PAGE ONE

ALPHA MODEL	Model angle of attack, deg
ALPHA PB	Support sting prebend angle, deg
CONFIGURATION	Model configuration (see Fig. 2)
DATA TYPE	Type of data tabulated
DEW PT	Free-stream flow frost point, °F
GROUP	Data group number
LOOP	Data point identification number
M(INF)	Free-stream Mach number
MU(INF)	Free-stream viscosity, $lbf\text{-}sec/ft^2$
NOSE RADIUS	Model nose tip radius, in.
P(INF)	Free-stream static pressure, psia
PO	Tunnel stilling chamber pressure, psia
POP	Free-stream total pressure downstream of a normal shock, psia
POO	Overhead probe pitot pressure, psia
PROBE STATION	Probe station location measured along model surface from model nose tip, in.
RE(INF)	Free-stream Reynolds number per foot
ROLL	Model roll angle, deg
TO	Tunnel stilling chamber temperature, °R
TOO	Unshielded thermocouple probe reading, °R
TRIP	Boundary-layer trip configuration - sphere and grit dimensions stated in inches
TWX	Model wall temperature at probe survey station, °R
U(INF)	Free-stream velocity, ft/sec
ZO	Pitot probe height above model surface, in.
ZOT	Height of unshielded thermocouple probe above model surface, in.

PRINTOUT PAGE TWO

All heading information is identical to page one.

TG-1 - TG-19	Gardon gage case temperature, °R

PRINTOUT PAGE THREE (UNSHIELDED TEMPERATURE PROBE CORRECTIONS)

All heading information is identical to page one.

A00 - A04	Calibration constants
ETAO	Effective probe recovery factor
LOOP	Data point identification number
MOI	Local Mach number at survey point
PO	Tunnel stilling chamber pressure, psia
POOI	Local interpolated pitot pressure, psia
ROD	Local Reynolds number at survey probe
TO	Tunnel stilling chamber temperature, °R
TOOI	Local corrected total temperature at survey point, °R
TOUM	Unshielded thermocouple probe reading, °R
UOI	Local flow velocity, ft/sec
XP	Probe longitudinal location, counts
ZOT	Height of unshielded thermocouple probe above model surface, in.

PRINTOUT PAGE FOUR (BOUNDARY-LAYER VALUES)

All heading information is identical to page one.

DEL	Boundary-layer thickness, in.
DEL*	Displacement thickness, in.
DEL2	Momentum thickness, in.
DEL3	Kinetic energy defect, in.
DEL4	Total enthalpy defect, in.
H1	Shape factor, DEL*/DEL2
H2	Shape factor, DEL2/DEL3
RHOED	Static density based on TED, Slugs/ft^3
TED	Total temperature, at boundary-layer edge, °R
UOED	Flow velocity at boundary-layer edge, ft/sec

ARO, INC - AEDC DIVISION
A SVERDRUP CORPORATION COMPANY
VON KARMAN GAS DYNAMICS FACILITY
ARNOLD AIR FORCE STATION, TENN

DATE COMPUTED 26-JUN-78
DATE RECORDED 30-JAN-78
TIME RECORDED 0:12:37

PROJECT NO V41B-W6A
SAMSO/DOTR HYPERSONIC TURBULENT BOUNDARY LAYER INVESTIGATION
PHASE I

GROUP 36
M(INF)= 5.95
RE(INF)= 4.731E+06 PER FT

ALPHA MODEL = -0.08 DEG.
ALPHA PB = 13.00 DEG.
ROLL = 90.36 DEG.

DEW PT=-22.00 (DEG F)

CONFIGURATION 7-DEG CONE

NOSE RADIUS, IN SHARP

TRIP NONE

DATA TYPE
OVERHEAD PROBE

PROBE STATION = 39.80 IN.

LOOP	PO (PSIA)	TO (DEGR)	PINF (PSIA)	POP (PSIA)	ZO (IN)	POO (PSIA)	POO/POP	ZOT (IN)	TOO (DEGR)	TOO/TO	PW1	TW1
1	249.52	847.7	0.166	7.661	0.0060	0.568	0.074	-0.0000	756.	0.893	0.332	742.
2	249.73	845.7	0.167	7.667	0.0135	1.383	0.180	0.0074	762.	0.900	0.332	742.
3	249.62	846.7	0.166	7.664	0.0255	2.219	0.289	0.0194	763.	0.901	0.332	742.
4	249.42	847.7	0.166	7.658	0.0335	2.517	0.328	0.0274	764.	0.902	0.333	742.
5	249.22	845.7	0.166	7.651	0.0435	2.738	0.356	0.0374	765.	0.903	0.333	742.
6	248.72	847.7	0.166	7.636	0.0535	2.942	0.383	0.0474	766.	0.904	0.332	742.
7	249.42	845.7	0.166	7.658	0.0640	3.188	0.415	0.0579	768.	0.907	0.332	742.
8	249.83	847.7	0.167	7.670	0.0735	3.425	0.446	0.0674	770.	0.909	0.332	742.
9	249.22	847.7	0.166	7.651	0.0840	3.692	0.481	0.0779	772.	0.912	0.332	742.
10	249.22	845.7	0.166	7.651	0.0945	3.938	0.513	0.0884	773.	0.913	0.332	742.
11	250.03	846.7	0.167	7.676	0.1035	4.205	0.547	0.0974	774.	0.914	0.334	742.
12	251.74	845.7	0.168	7.729	0.1240	4.812	0.626	0.1179	777.	0.917	0.336	742.
13	253.25	842.7	0.169	7.775	0.1430	5.368	0.699	0.1369	780.	0.921	0.337	742.
14	251.94	846.7	0.168	7.735	0.1630	5.993	0.780	0.1569	784.	0.926	0.336	742.
15	251.74	848.7	0.168	7.729	0.1845	6.666	0.868	0.1784	789.	0.932	0.335	742.
16	249.02	848.7	0.166	7.645	0.2030	7.245	0.943	0.1969	791.	0.934	0.333	742.
17	248.42	845.7	0.166	7.627	0.2250	8.002	1.042	0.2189	793.	0.936	0.332	742.
18	249.32	847.7	0.166	7.655	0.2440	8.761	1.140	0.2379	794.	0.938	0.332	742.
19	248.62	847.7	0.166	7.633	0.2635	9.500	1.237	0.2574	794.	0.938	0.332	742.
20	252.14	843.7	0.168	7.741	0.2835	10.384	1.352	0.2774	793.	0.936	0.335	742.
21	251.74	846.7	0.168	7.729	0.3035	10.997	1.431	0.2974	792.	0.935	0.335	742.
22	250.93	844.7	0.167	7.704	0.3230	11.498	1.497	0.3169	791.	0.934	0.335	742.
23	251.44	845.7	0.168	7.719	0.3425	11.888	1.547	0.3364	790.	0.933	0.335	742.
24	250.73	847.7	0.167	7.698	0.3640	12.122	1.578	0.3579	789.	0.932	0.335	742.
25	251.14	844.7	0.167	7.710	0.3840	12.252	1.595	0.3779	788.	0.930	0.334	742.
26	250.83	845.7	0.167	7.701	0.4025	12.314	1.603	0.3964	787.	0.929	0.335	742.
27	251.14	847.7	0.167	7.710	0.5050	12.336	1.606	0.4989	787.	0.929	0.334	742.
28	250.33	847.7	0.167	7.685	0.6050	12.298	1.601	0.5988	787.	0.929	0.334	742.
29	250.93	847.7	0.167	7.704	0.7030	12.272	1.597	0.6968	787.	0.929	0.334	742.
30	250.13	845.7	0.167	7.679	1.0045	12.218	1.590	0.9983	787.	0.929	0.334	742.
31	250.43	847.7	0.167	7.689	2.0020	11.814	1.538	1.9957	787.	0.929	0.333	742.
32	250.13	845.7	0.167	7.679	3.0045	11.247	1.464	2.9981	787.	0.929	0.334	742.
33	249.62	845.7	0.166	7.664	4.0020	7.662	0.997	3.9955	788.	0.930	0.331	742.

IV-8. Sample Data: Overhead Probe Flow-Field Data

PAGE TWO GROUP 36

LOOP	PO (PSIA)	TO (DEGR)	PINF (PSIA)	POP (PSIA)	ZO (IN)	POO (PSIA)	POO/POP	ZOT (IN)	TOO (DEGR)	TOO/TO	PW1	TW1
34	250.23	847.7	0.167	7.682	4.4990	7.650	0.996	4.4925	787.	0.929	0.333	742.
35	249.32	847.7	0.166	7.655	0.9985	12.100	1.575	0.9923	787.	0.929	0.333	742.
36	249.02	845.7	0.166	7.645	0.2490	12.066	1.571	0.2429	789.	0.932	0.333	742.

MEAN VALUES

PO = 250.23 PSIA
TO = 846.5 DEGR
P(INF)= 0.1668 PSIA
RE(INF)= 0.473E+07 PER FT
MU(INF)= 0.843E-07 LBF-SEC/FT2
XP = -1. CTS

U(INF)= 2985.5 FT/SEC
Q(INF)= 4.135 PSIA
T(INF)= 104.8 DEGR
POP = 7.68 PSIA
RHO(INF)= 0.134E-03 SLUGS/FT3

DATE COMPUTED 26-JUN-78
DATE RECORDED 30-JAN-78
TIME RECORDED 0:12:37

ARO, INC - AEDC DIVISION
A SVERDRUP CORPORATION COMPANY
VON KARMAN GAS DYNAMICS FACILITY
ARNOLD AIR FORCE STATION, TENN

PROJECT NO V41B-W6A
SAMSO/DOTR HYPERSONIC TURBULENT BOUNDARY LAYER INVESTIGATION
PHASE I

GROUP 36
M(INF)= 5.95
RE(INF)= 4.731E+06 PER FT

ALPHA MODEL = -0.08 DEG.
ALPHA PB = 13.00 DEG.
ROLL = 90.36 DEG.

DEW PT=-22.00 (DEG F)

CONFIGURATION
7-DEG CONE

NOSE RADIUS, IN
SHARP

TRIP
NONE

DATA TYPE
OVERHEAD PROBE

PROBE STATION = 39.80 IN.

LOOP	TG-1 DEGR	TG-2 DEGR	TG-3 DEGR	TG-4 DEGR	TG-5 DEGR	TG-6 DEGR	TG-7 DEGR	TG-8 DEGR	TG-9 DEGR	TG-10 DEGR	TG-11 DEGR	TG-12 DEGR	TG-13 DEGR	TG-14 DEGR	TG-15 DEGR	TG-16 DEGR	TG-17 DEGR	TG-18 DEGR	TG-19 DEGR
1	742.	749.	750.	752.	752.	753.	753.	753.	754.	753.	754.	755.	756.	758.	759.	764.	764.	743.	738.
2	742.	749.	750.	752.	752.	753.	752.	753.	754.	753.	754.	755.	756.	758.	759.	764.	764.	743.	738.
3	742.	749.	750.	752.	752.	753.	752.	753.	754.	753.	754.	755.	756.	757.	759.	764.	764.	743.	738.
4	742.	749.	750.	752.	752.	753.	752.	753.	754.	753.	754.	755.	756.	757.	759.	764.	764.	743.	738.
5	742.	749.	750.	752.	752.	753.	752.	753.	754.	753.	754.	755.	756.	757.	759.	764.	764.	743.	738.
6	742.	749.	750.	752.	752.	753.	752.	753.	754.	753.	754.	755.	756.	758.	759.	764.	764.	743.	738.
7	742.	749.	750.	752.	752.	753.	752.	753.	754.	753.	754.	755.	756.	757.	759.	764.	764.	743.	738.
8	742.	749.	750.	752.	752.	753.	752.	753.	754.	753.	754.	755.	756.	757.	759.	764.	764.	743.	738.
9	742.	749.	750.	752.	752.	753.	752.	753.	754.	753.	754.	755.	756.	757.	759.	764.	764.	743.	738.
10	742.	749.	750.	752.	752.	753.	752.	753.	754.	753.	754.	755.	756.	758.	759.	764.	764.	743.	738.
11	742.	749.	750.	751.	752.	753.	752.	753.	754.	753.	754.	755.	756.	757.	759.	764.	764.	743.	738.
12	742.	749.	750.	751.	752.	753.	752.	753.	754.	753.	754.	755.	756.	757.	759.	764.	764.	743.	738.
13	742.	749.	750.	751.	752.	752.	752.	752.	753.	752.	754.	755.	755.	757.	759.	763.	764.	743.	738.
14	742.	748.	750.	751.	751.	752.	752.	752.	753.	752.	754.	755.	755.	757.	758.	763.	764.	743.	738.
15	742.	748.	750.	751.	751.	752.	752.	752.	753.	752.	754.	755.	755.	757.	758.	763.	764.	743.	738.
16	742.	749.	750.	751.	752.	752.	752.	753.	754.	752.	754.	755.	756.	757.	759.	763.	764.	743.	738.
17	742.	749.	750.	751.	752.	753.	752.	753.	754.	753.	754.	755.	756.	757.	759.	764.	764.	743.	738.
18	742.	749.	750.	751.	752.	753.	752.	753.	754.	753.	754.	755.	756.	757.	759.	764.	764.	743.	738.
19	742.	749.	750.	751.	752.	753.	752.	753.	754.	753.	754.	755.	756.	757.	759.	764.	764.	743.	738.
20	742.	749.	750.	751.	751.	752.	752.	752.	753.	752.	754.	755.	756.	757.	759.	763.	764.	743.	738.
21	742.	749.	750.	751.	751.	752.	752.	752.	753.	752.	754.	755.	756.	757.	758.	763.	764.	743.	738.
22	742.	749.	750.	751.	751.	752.	752.	752.	753.	752.	754.	755.	755.	757.	759.	763.	764.	743.	738.
23	742.	749.	750.	751.	751.	752.	752.	752.	753.	752.	754.	755.	756.	757.	759.	763.	764.	743.	738.
24	742.	749.	750.	751.	751.	752.	752.	752.	753.	753.	754.	755.	756.	757.	759.	763.	764.	743.	738.
25	742.	749.	750.	751.	752.	752.	752.	753.	754.	752.	754.	755.	756.	757.	759.	763.	764.	743.	738.
26	742.	749.	750.	751.	752.	752.	752.	752.	753.	752.	754.	755.	756.	757.	759.	763.	764.	743.	738.
27	742.	749.	750.	751.	752.	753.	752.	753.	754.	753.	754.	755.	756.	757.	759.	764.	764.	743.	738.
28	742.	749.	750.	751.	752.	753.	752.	753.	753.	753.	754.	755.	756.	757.	759.	764.	764.	743.	738.
29	742.	749.	750.	751.	752.	753.	752.	753.	753.	753.	754.	755.	756.	757.	759.	764.	764.	743.	738.
30	742.	749.	750.	751.	752.	753.	752.	753.	753.	753.	754.	755.	756.	757.	759.	764.	764.	743.	738.
31	742.	749.	750.	751.	752.	753.	752.	753.	754.	753.	754.	755.	756.	757.	759.	764.	764.	743.	738.
32	742.	749.	750.	752.	752.	753.	752.	753.	754.	753.	754.	755.	756.	757.	759.	764.	764.	743.	738.
33	742.	749.	750.	752.	752.	753.	753.	753.	754.	753.	754.	755.	756.	758.	759.	764.	764.	743.	738.
34	742.	749.	750.	752.	752.	753.	753.	753.	754.	753.	754.	755.	756.	758.	759.	764.	764.	743.	738.
35	742.	749.	751.	752.	752.	753.	753.	753.	754.	753.	754.	756.	756.	758.	759.	764.	765.	744.	738.
36	742.	749.	751.	752.	752.	753.	753.	753.	754.	753.	754.	756.	756.	758.	759.	764.	765.	744.	738.

ARO, INC - AEDC DIVISION
A SVERDRUP CORPORATION COMPANY
VON KARMAN GAS DYNAMICS FACILITY
ARNOLD AIR FORCE STATION, TENN

DATE COMPUTED 26-JUN-78
DATE RECORDED 30-JAN-78
TIME RECORDED 0:12:37

PROJECT NO V41B-W6A
SAMSO/DOTR HYPERSONIC TURBULENT BOUNDARY LAYER INVESTIGATION
PHASE I

GROUP 36
M(INF)= 5.95
RE(INF)= 4.741E+06 PER FT

ALPHA MODEL = -0.08 DEG.
ALPHA PB = 13.00 DEG.
ROLL = 90.36 DEG.

DEW PT=-22.00
(DEG F)

CONFIGURATION
7-DEG CONE

NOSE RADIUS, IN
SHARP

TRIP
NONE

UNSHIELDED TEMPERATURE PROBE CORRECTIONS   PROBE STATION = 39.80 IN.
OVERHEAD PROBE

LOOP	ZOT (IN)	PO (PSIA)	TO (DEGR)	POOI (PSIA)	POOI/PO	MOI	ROD	ETAO	TOO/TO	TOOI (DEGR)	TOOI/TO	UOI (FT/SEC)
1	-0.0000	249.52	847.7	0.331	0.0013	0.09	3.84	0.925	0.893	756.	0.893	123.09
2	0.0074	249.73	845.7	0.725	0.0029	1.12	50.97	0.922	0.900	774.	0.914	1361.92
3	0.0194	249.62	846.7	1.798	0.0072	1.95	103.07	0.920	0.901	790.	0.933	2024.54
4	0.0274	249.42	847.7	2.292	0.0092	2.23	124.14	0.920	0.902	795.	0.940	2181.36
5	0.0374	249.22	845.7	2.604	0.0104	2.38	137.08	0.920	0.903	799.	0.944	2260.39
6	0.0474	248.72	847.7	2.818	0.0113	2.49	145.71	0.919	0.904	801.	0.947	2307.96
7	0.0579	249.42	845.7	3.046	0.0122	2.59	154.55	0.919	0.907	805.	0.951	2354.98
8	0.0674	249.83	847.7	3.273	0.0131	2.69	163.36	0.919	0.909	808.	0.955	2398.05
9	0.0779	249.22	847.7	3.537	0.0141	2.80	173.45	0.919	0.912	812.	0.959	2442.60
10	0.0884	249.22	845.7	3.796	0.0152	2.91	183.48	0.919	0.913	814.	0.962	2480.67
11	0.0974	250.03	846.7	4.025	0.0161	3.00	192.29	0.918	0.914	816.	0.965	2511.77
12	0.1179	251.74	845.7	4.632	0.0185	3.23	215.29	0.918	0.917	822.	0.971	2584.18
13	0.1369	253.25	842.7	5.190	0.0207	3.42	235.94	0.918	0.921	827.	0.977	2640.28
14	0.1569	251.94	846.7	5.803	0.0232	3.63	258.10	0.917	0.926	834.	0.985	2694.37
15	0.1784	251.74	840.7	6.476	0.0259	3.84	281.69	0.917	0.932	841.	0.993	2746.57
16	0.1969	249.02	848.7	7.055	0.0282	4.01	302.67	0.916	0.934	844.	0.998	2782.18
17	0.2189	248.42	845.7	7.792	0.0311	4.22	329.50	0.916	0.936	848.	1.002	2821.04
18	0.2379	249.32	847.7	8.518	0.0340	4.41	356.10	0.916	0.938	851.	1.005	2852.50
19	0.2574	248.62	847.7	9.269	0.0370	4.61	384.08	0.915	0.938	852.	1.007	2879.10
20	0.2774	252.14	843.7	10.114	0.0404	4.82	416.10	0.915	0.936	852.	1.007	2903.16
21	0.2974	251.74	846.7	10.810	0.0432	4.98	442.72	0.914	0.935	852.	1.007	2920.10
22	0.3169	250.93	844.7	11.341	0.0453	5.10	463.18	0.914	0.934	852.	1.006	2931.20
23	0.3364	251.44	845.7	11.766	0.0470	5.20	479.69	0.914	0.933	851.	1.006	2938.97
24	0.3579	250.73	847.7	12.055	0.0482	5.27	491.19	0.914	0.932	851.	1.005	2943.33
25	0.3779	251.14	844.7	12.212	0.0486	5.30	497.78	0.914	0.930	850.	1.004	2944.72
26	0.3964	250.83	845.7	12.293	0.0491	5.32	501.56	0.914	0.929	849.	1.003	2944.52
27	0.4989	251.14	847.7	12.334	0.0493	5.33	503.10	0.914	0.929	849.	1.003	2945.35
28	0.5988	250.33	847.7	12.300	0.0492	5.32	501.81	0.914	0.929	849.	1.003	2944.66
29	0.6968	250.93	847.7	12.273	0.0490	5.31	500.82	0.914	0.929	849.	1.003	2944.12
30	0.9983	250.13	845.7	12.219	0.0488	5.30	498.78	0.914	0.929	849.	1.003	2943.01
31	1.9957	250.43	847.7	11.817	0.0472	5.21	483.75	0.914	0.929	848.	1.002	2934.52
32	2.9981	250.13	845.7	11.250	0.0450	5.08	462.85	0.914	0.929	848.	1.001	2921.69

LOOP	ZOT (IN)	PO (PSIA)	TO (DEGR)	POOI (PSIA)	POOI/PO	MOI	ROD	ETAO	TOO/TO	TOOI (DEGR)	TOOI/TO	UOI (FT/SEC)
33	3.9955	249.62	845.7	7.686	0.0307	4.19	327.96	0.916	0.930	843.	0.995	2807.44
34	4.4925	250.23	847.7	7.650	0.0306	4.18	327.13	0.916	0.929	842.	0.994	2804.08
35	0.9923	249.32	847.7	12.220	0.0488	5.30	498.82	0.914	0.929	849.	1.003	2943.03
36	0.2429	249.02	845.7	8.718	0.0348	4.47	366.28	0.915	0.932	846.	0.999	2850.97

CALIBRATION CONSTANTS
A00= 9.261E-01 A01= -5.840E-04 A02= 0.000E+00 A03= 0.000E+00 A04= 0.000E+00

MEAN VALUES

PO =	250.23 PSIA	U(INF)=	2985.5 FT/SEC
TO =	846.5 DEGR	Q(INF)=	4.135 PSIA
P(INF)=	0.1668 PSIA	T(INF)=	104.8 DEGR
RE(INF)=	0.473E+07 PER FT	POP =	7.68 PSIA
MU(INF)=	0.843E-07 LBF-SEC/FT2	RHO(INF)=	0.134E-03 SLUGS/FT3
XP =	-1. CTS		

ARO, INC - AEDC DIVISION
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DATE COMPUTED 26-JUN-78
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PROJECT NO V41B-W6A
SAMSO/DOTR HYPERSONIC TURBULENT BOUNDARY LAYER INVESTIGATION
PHASE I

GROUP 36
M(INF)= 5.95
RE(INF)= 4.731E+06 PER FT

ALPHA MODEL = -0.08 DEG.
ALPHA PB = 13.00 DEG.
ROLL = 90.36 DEG.

DEW PT=-22.00
(DEG F)

CONFIGURATION
7-DEG CONE

NOSE RADIUS, IN
SHARP

TRIP
NONE

DATA TYPE
OVERHEAD PROBE

PROBE STATION = 39.80 IN.

BOUNDARY LAYER VALUES

```
DEL   =  0.3491 IN.
DEL*  =  0.1480 IN.
DEL2  =  0.0126 IN.
DEL3  =  0.0232 IN.
DEL4  =  0.0026 IN.
H1    = 11.7809
H2    =  0.5416
TED   =   851.0 DEGR
UOED=    2941.3 FT PER SECOND
RHOED= 2.130E-04 SLUGS PER FT3
```

MEAN VALUES

```
PO     = 280.23 PSIA               U(INF)= 2985.5 FT/SEC
TO     =    846.5 DEGR             Q(INF)=  4.135 PSIA
P(INF)=   0.1668 PSIA              T(INF)=  104.8 DEGR
RE(INF)=  0.473E+07 PER FT         POP =    7.68 PSIA
MU(INF)=  0.843E-07 LBF-SEC/FT2    RHO(INF)=  0.134E-03 SLUGS/FT3
XP =     -1. CTS
```